Offsetting CO_2 Emissions

Tree Planting on the Prairies

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Introduction

The nations of the world agreed in 1992 at the Earth Summit in Rio de Janeiro to take steps to stabilize and reduce the net emissions of carbon dioxide. Trees have often been discussed in this context since, by fixing carbon, they offset carbon emissions by fossil fuels and can be used as an alternative renewable biofuel, replacing the use of fossil fuels. The degree to which tree-planting in the Prairie Provinces will be adopted as a carbon offset in the coming years will depend on technology, programs, policies and legislation.

Canada has agreed to reduce carbon emissions to 1990 levels by the year 2000. Tree planting can be seen as one of the ways of achieving this goal. The ability of trees on the Canadian prairies to offset rising levels of carbon dioxide in the atmosphere is the topic of this report.

In this report a brief discussion on what the current levels of carbon emissions are for the prairies and for Canada as a whole is provided. Policies and practices in the European Union, the United States, and Canada will be reviewed to determine the feasibility of tree-planting as well as the best strategy to employ. For Canada this will include policies which have an indirect effect on the tree population and alternative energy sources through incentives or disincentives. This information is important in determining the economic and political feasibility of implementing a tree planting initiative.

The benefits of planted trees will be discussed not only in economic terms, but also from a social and environmental perspective. Highlighting the social and environmental benefits of trees will contribute towards evaluating opportunities for tree planting on the Prairies.

Study Assumptions

Prairies does not refer to the Prairie Provinces but to the prairie ecozone, hence we have not discussed the potential of the boreal forests to sequester carbon. This assumption was based on the statement of work and the fact that this is being done for PFRA which works in the prairie ecozone.

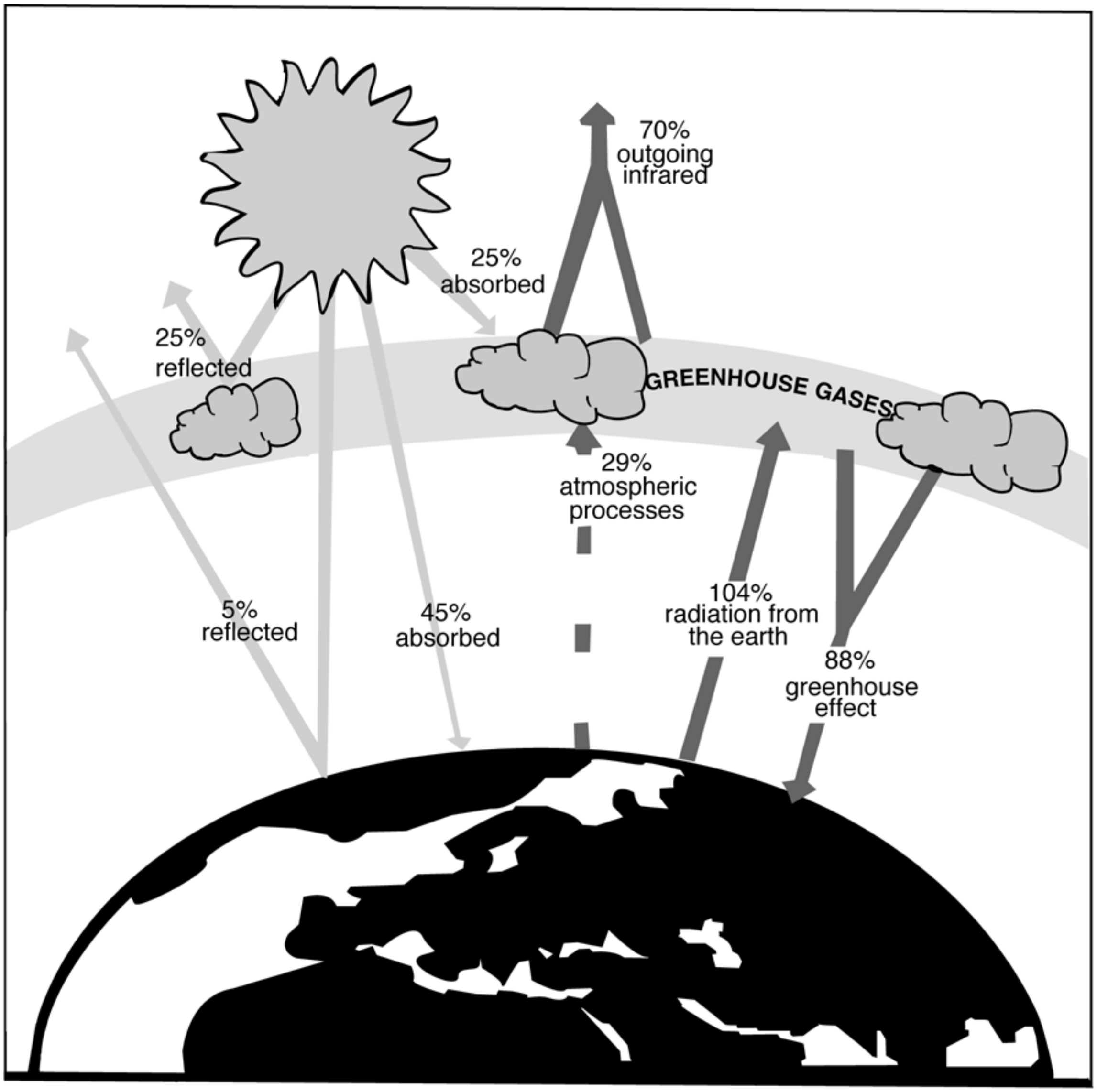
This report is for a general audience, and therefore does not go into technical details of photosynthesis, soil carbon dynamics and other complex processes.

The effects of climate change on the prairies, or the economic and social effects that climate change could induce is not outlined in this report.

Background

Various gases contribute to the greenhouse effect. The primary focus of this study is on CO_2 emissions' contribution to greenhouse warming and what can be done to increase CO_2 sinks through the use of tree planting.

Figure 1. Greenhouse effect.



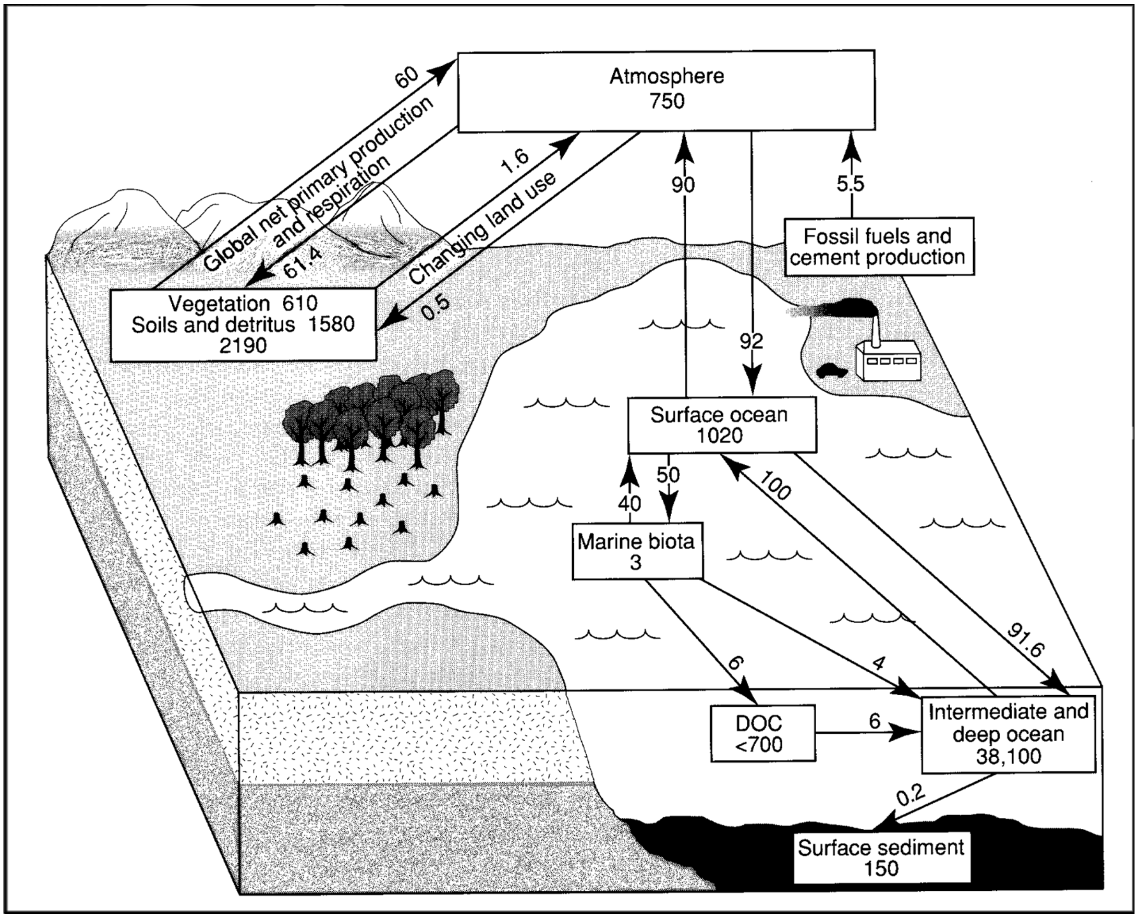
Source: Royal Society of Canada (1993).

The greenhouse effect is a natural phenomenon that is vital to life on Earth. The sun irradiates the Earth and about 70% of the incoming radiation are absorbed by gases in the atmosphere and by the planet's surface. The result is similar to the action of a greenhouse where warm air is held inside the greenhouse. The average temperature of the Earth's atmosphere is raised by the energy trapped by these gases, maintaining the Earth's temperature within a tolerable range. This phenomenon is known as the "greenhouse effect" and causes the earth's surface to be about 33^{o}C warmer than it would be otherwise. How solar energy and surface radiation is absorbed and reflected in the greenhouse effect is depicted in Figure 1.

The most predominate greenhouse gases (GHG) are water vapour (H_2O) and carbon dioxide (CO_2). Other greenhouse gases include chlorofluorocarbons (CFCs), methane

(CH_4), nitrous oxide (N_2O) and ozone (O_3). Except for CFCs, all GHG occur naturally. CO_2 is the most important GHG because of its long life span in the atmosphere.

Figure 2: The Generalized Carbon Cycle.



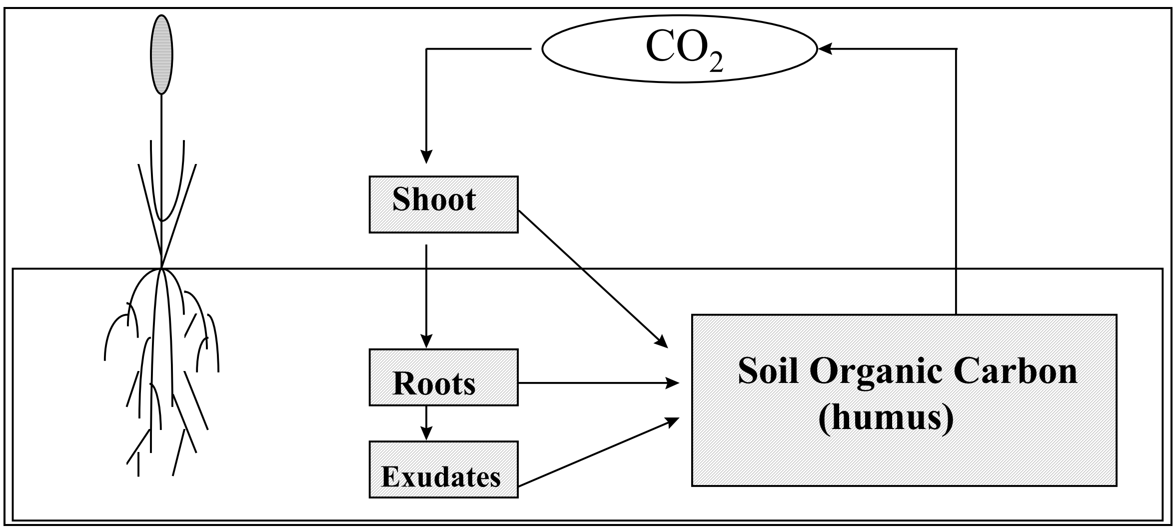
Source: Houghton et al. (1995).

Carbon emissions into the atmosphere are generated by natural and human activities. Natural reactions are part of a large, complex cycle of carbon generation and absorption referred to as the carbon cycle. Carbon is absorbed through three major carbon stores, or "sinks" in nature. These are the oceans, the atmosphere, and the terrestrial system, including forests, plants, soils and geological forms such as fossil fuel stores. This global carbon cycle is illustrated in Figure 2.

CO_2 is produced when any substance containing carbon is burned or decays. Human activity affects the natural carbon cycle through land use changes and fossil fuel use, which results in a build-up of atmospheric carbon.

Plants acquire CO_2 from the atmosphere through photosynthesis to produce carbohydrates some of which are converted into new plant tissues. When this happens, carbon is fixed into trees accumulating biomass in the form of organic carbon. While growth occurs, CO_2 continues to be absorbed. The rate of absorption will depend on the rate of growth of the plant. As long as plant growth exceeds decomposition, the net rate of carbon sequestration will be positive. Throughout the life of the plant and after the plant dies, plant residues, roots and exudates are decomposed by microbes. Some of the carbon is released back into the atmosphere as CO_2 through respiration and some becomes part of the soil in the form of soil organic matter (SOM). Soil organic matter decomposes very slowly and hence, soil becomes a substantial reservoir of carbon. Levels of soil carbon are dependent on many variables: microbial activity, temperature, moisture, and soil disturbances such as agricultural activity, clearing of forests, or fires. Figure 3 outlines the interaction between plants, soil and the atmosphere as carbon is cycled.

Figure 3. Plant-Soil-Atmosphere Carbon Cycle.



The ability of the soil and plants to fix carbon is attracting more and more attention as the topic of global warming becomes a contentious issue. As yet, scientists cannot predict with certainty whether a human-induced warming effect due to rising levels of GHG has begun; how much or at what rate the earth might warm; and how the climate change will affect individual countries or regions over time. Climate and weather patterns change naturally and it is difficult to separate normal shifts from human induced changes. Weather observation records point to global warming of about $0.5^{O}C$ over the past century. There is much contradictory evidence and analytical forecasting is uncertain. Scientists agree that atmospheric concentrations of carbon dioxide, methane, chlorofluorocarbons and nitrous oxide are increasing and that these concentrations may possibly lead to higher global temperatures.

Assuming that global warming is taking place, warming is expected to be greater at higher latitudes and temperature increases are expected to be accompanied by unpredictable changes in climatic conditions. Patterns of agriculture and water availability will be affected. Altered climates could affect world food security by changing agricultural productivity and would affect the productivity and biological diversity of forests and other natural ecosystems.

Controlling Rising CO_2 Levels

Three ways of combating rising CO_2 emissions are:
- Substitution of lower carbon energy sources;
- Reduction of the activity causing the emissions; or
- Sequestration of CO_2 .

Substitution of Lower Carbon Energy Sources

Substitution of lower carbon energy sources can be done through switching from high-carbon fuels to lower-carbon fuels or switching to non-carbon sources of energy. Fuel switching involves: 1) replacing fossil fuels, such as coal or oil, with lower carbon fuels such as natural gas; 2) replacing fossil fuels with biomass such as wood or ethanol; and 3) replacing fossil fuels and/or biomass with other energy sources such as solar, wind, geothermal, nuclear, tidal and hydro. The rationale behind such actions is that biomass energy and biofuels emit less carbon than the burning of fossil fuels and are releasing carbon that is in the carbon cycle. Carbon contained in biomass is not fixed and removed from the carbon cycle as is the case with fossil fuels before they are burnt. Furthermore, no net CO_2 emissions are released during burning since any CO_2 emitted is reabsorbed by growing crops

Reduction of the Activity Causing the Emissions

Reduction of the activity causing the emissions can take place though a wide range of means. These reductions would include changes in consumption patterns, more efficient generation of electricity and greater efficiency in energy use.

Most studies have concluded that reduced energy use is likely to be more important than substitution of lower carbon energy sources in reducing CO_2 emissions but both will be required if overall costs are to be minimized (Nichols & Harrison, 1991).

Sequestration of CO_2

Sequestration of CO_2 is the process of removing CO_2 from the atmosphere and into other mediums, such as the oceans, soil and biomass of trees and plants. The speed of this natural process can be altered by human activity, and can lead to increasing or decreasing rates of sequestration. Typically, human activity results in a decreasing rate of carbon sequestering, but certain management practices can increase the net uptake of atmospheric CO_2 by vegetation and soils.

There is some uncertainty as to how natural carbon fluxes might be affected by potential climate change. If the balance of natural fluxes were disrupted, the future growth rate of atmospheric CO_2 could dramatically accelerate or decrease in a way that could make policies about human induced emissions irrelevant.

Human activities add to the natural occurrence of carbon dioxide in the atmosphere through the burning of fossil fuels, the disturbance of carbon sinks and the use of industrial chemicals and fertilizers[1]. Coal, gas and oil are burned primarily for transportation and power generation and are known to contribute significantly to CO_2 concentrations in the atmosphere. Carbon sinks are affected by soil disturbances and ecosystem conversion such as deforestation or conversion of prairie and steppe ecosystems into agricultural crops. Disturbing carbon sinks both emits CO_2 and reduces the amount of carbon dioxide that can be sequestered affecting their potential to fight rising CO_2 levels. It is estimated that approximately 2 billion tonnes of carbon are released globally into the atmosphere annually due to tropical deforestation and changing land management practices (Houghton et al., 1990).

It is possible for humans to compensate for the effect of these activities by creating new carbon sinks or improving existing ones. At this point no way has been found in which to raise the potential of oceans to absorb more carbon. However, the two main ways to increase carbon sequestration are to plant trees to compensate for deforestation and harvesting, and to change land management practices to maximize the soil organic matter.

International Policies

The international community has recognized the need to decrease carbon emissions and has signed agreements which support the adoption of various activities which reduce or offset carbon dioxide emissions. Individual governments are now in the process of formulating policy and legislation which will help them meet the commitments made in these international agreements. What follows is a brief overview of the international dialogue on climate change and the various policies, statutes and actions which the governments of Europe, the United States and Canada have implemented.

Commitments and Goals

Canada has taken a strong leadership role internationally to address greenhouse warming. Canada helped to broker a consensus on an emissions protocol for developing countries, and on the implementation of pilot projects for the sharing of green technologies. Canada has committed to a number of international agreements that recognized the need to reduce CO_2 emissions.

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1 Other sources of GHG also include rotting garbage, volcanoes, forest fires, decaying plants and respiration by animals.

- In 1988, at the World Conference on the Changing Atmosphere in Toronto, it was suggested for the first time that CO_2 emissions be reduced 20% from their 1988 levels by the year 2005.
- The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by UNEP and the World Meteorological Organization to assess existing scientific information on climate change, assess the environmental and socio-economic impacts of climate change and to advise the international community on the basis of that knowledge.
- In 1987, Canada signed the Montreal Protocol, agreeing to reduce the use of chlorofluorocarbons (CFCs).
- In 1990 Canada strengthened the Montreal Protocol by agreeing to eliminate the use of the most damaging CFCs by 1997.
- In 1992 Canada announced that it would eliminate use of CFCs by 1996.

In 1992 at the Earth Summit in Rio de Janeiro, Canada signed the Framework Convention on Climate Change (FCCC) agreeing to reduce pollution, report on their actions, co-operate in research and carry out education on climate change. Canada was one of the first countries in Rio to sign the declaration agreeing to stabilize GHG emissions at 1990 levels by the year 2000. The Convention recognizes the historical responsibility of industrialized countries for the current levels of human emissions of GHGs. Attention was focused on forests around the world and their role in the global carbon cycle. The FCCC stresses the potential role of carbon sinks to mitigate the accumulation of GHG in the atmosphere.

In 1995 at the First Conference of the Parties to the Framework Convention in Berlin, Canada agreed that current commitments to reduce GHG are inadequate. A draft program of Canada's National Action Program on Climate Change (NAPCC) was approved and tabled at the Conference. Negotiations towards a protocol for quantified reduction commitments beyond the year 2000 began. Canada also agreed to a pilot phase for Joint Implementation where developed countries would get credit for sponsoring emissions-reducing measures in lesser developed countries. Joint Implementation was formally adopted into the text of the Framework Convention on Climate Change in 1992 and refers to international co-operation between two or more governments who agree to implement strategies to reduce or sequester greenhouse gas emissions. Canada has established its own Joint Implementation Pilot Initiative as part of its National Action Program. (Canada, 1995; Environment Canada, 1995; SOE Report, 1995).

The European Union

The European Union has fifteen Member States (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden and the United Kingdom). The first aim of the Union is to lay the foundation of an ever-closer union between the peoples of Europe. The signing of the Maastricht Treaty (also known as the Treaty on European Union) in February, 1992 has laid the legal foundation for doing so. A single European market and European Economic Area is now in existence and should lead to economic and monetary union and, ultimately a single currency in 1997. Balanced and sustainable economic and social progress is to be promoted through these actions (European Commission, 1996a & b). Consequently, the Union formulates policy and legislation in all areas relating to its Members including the environment.

Environmental concerns are not only a priority but are also inseparable from most other policy areas for the European Union. This stance was given momentum in 1972 in a meeting of heads of European Community states in Paris. They agreed that economic growth was not an end in itself but that it should lead to an improvement in the quality of life and standard of living. As such, particular attention should be paid to protecting the environment. The Single European Act (1987) reinforced this by requiring that environmental protection form a part of the Community's other policies. It also requires that environmental protection be pursued as an end in itself. The Maastricht Treaty extends the Union's environmental policy objectives to include the goals of sustainable growth and the resolution of global environmental problems (Vohrer, 1991; Commission of the European Communities, 1992).

Concern about global warming has prompted the Union to adopt policies relating to measures which it can undertake itself, as well as global responses which need to be negotiated multilaterally. A joint Council of Community Environment and Energy Ministers convened in 1990 agreed on a common approach to the issue and a Community-wide response to this issue. The goal is to take action that will stabilize carbon dioxide emissions at 1990 levels by 2000 in the Community as a whole. Potential climate change linked to the greenhouse gas effect will be built into future policy formulation. It has also become official policy that action needs to be taken to increase energy savings, improve energy efficiency and promote the development and use of non-fossil energy sources. This would address all human activities which contribute to the problem, including energy, transport, agriculture and industry (Commission of the European Communities, 1992; Samaras & Zierok, 1992)

Action taken in any one of these sectors is to be based upon an equitable burden sharing arrangement according to each state's ability to bring about an improvement in the situation. Measures are also to be co-ordinated and policies within Member states are to be harmonized in order to achieve the maximum results possible. Thus, collective policies have been developed for the transport and energy sector which are most responsible for contributing to global warming. Such measures in the transport sector include permitting national phased tax increases on fossil fuel oil in keeping with pollution of the environment, a weight distance tax[2] on vehicles community wide, and restructuring transport performance with the aid of economic and fiscal instruments. Priority is being given to encouraging energy savings and renewable energy use by charging for environmental pollution as well as restructuring energy tariffs to reward energy saving. A standardized tax on fossil fuel for primary consumption is also being suggested. As well,

[2] A weight distance tax is differentiated according to the weight capacity of the vehicle and the distance travelled. All things being equal, a heavier vehicle will consume more fuel and thus is subject to a higher carbon tax.

Member states are required to adopt targets and strategies that will limit greenhouse gas emissions as soon as possible. In keeping with a commitment to a global response, Member states are expected to collaborate internationally in the fight against human-induced climate change. The Community is especially committed to the transfer of energy planning and technology to the developing countries.

The European Union (EU), thus far, has passed legislation and formulated policy on climate change issues. Practices have not specifically been adopted by the Union. However, it has set up various programs which provide a support structure for Member states to take action. This is in accordance with the principle of subsidiarity whereby policy, legislation and practices should be applied at the source of the problem. Member states are more able to tackle emissions at their source within their own country. It is important to note, however, that all legislation passed in member states is subservient to EU legislation. Thus EU legislation and policies form the basis for practices adopted within Member states. Hence it will be useful to review some of the programs that the EU has and the practices which have been adopted by these Members.

In an effort to combine the goals of controlling carbon emissions and increasing energy efficiency, the Union has proposed a combined carbon and energy tax. Carbon would be taxed at double the rate for non-carbon fuels (nuclear) and renewable energy sources would be exempt. This proposal has not received wide-spread acceptance and has not yet been implemented. The THERMIE program aimed at innovative energy technologies has been successful, however. Technologies funded through THERMIE have led to a reduction in carbon emissions of 3 million tonnes. This new program not only supports innovation but also promotes the implementation of these technologies in the market place. The European Investment Bank also offers loans under advantageous conditions for investments in energy efficiency. SAVE is a medium to long-term program which endeavours to create a more positive environment for energy efficiency by setting standards and improving the quality of information available to consumers. Finally, the ALTENER program will limit the emissions of CO_2 by promoting the development of renewable energy.

Different Member states have opted to use differing methods for tackling climate change problems. Italy and Germany are both implementing co-generation schemes for energy production. Germany has also adopted improved soil conservation techniques to protect soil carbon and a feebate[3] system which encourages vehicle owners to use catalytic converters. The Netherlands and Germany are involved in an international project where 2 thousand hectares per year of the tropics will be reforested to offset carbon emissions.

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[3] Feebates refers to a system where producers of consumers of certain substances are required to pay a certain rate for that action regardless of the legal limit permitted. Those who consume/produce less of the substance than the legal limits are then compensated for restraint. Those consuming/producing more than the legal limit receive little or no compensation depending on how the system is set up.

One of Ireland's greatest efforts in combating CO_2 emissions is afforestation and reforestation. The government's target is to plant trees on 30,000 hectares a year. Other Irish actions include fuel switching from coal to natural gas, and participation in the EU SAVE and ALTENER programs. Sweden's efforts have concentrated on a carbon tax which has been in existence since 1991[4].

The United States

At Earth Day 1993, President Clinton announced that the U.S. would comply with the Framework Convention on Climate Change agreed to in Rio in 1992. Accordingly, the Federal Government has adopted a series of policies, legislation and practices which work towards reducing net U.S. greenhouse gas emissions to 1990 levels[5] by 2000. Clinton's Climate Change Action Plan forms the foundation of the Federal approach.

The goal of U.S. climate change policy is to reduce the emission of greenhouse gases and conserve energy. The federal and states departments are supposed to apply measures to all sectors of the economy that emit greenhouse gases, and co-ordinate multiple programs. A collective effort is considered desirable since it is assumed that using measures on their own will only result in a modest impact on climate change. Investing in clean air and renewable energy technologies is also considered to be an important policy objective. Ideally, research and development should lead to the creation of new jobs as well. A commitment to monitor, evaluate and adjust current policies related to greenhouse gas emissions has been made by President Clinton (Clinton & Gore, 1993; US.EPA, 1990)

Internationally, the U.S. has committed to the prevention, mitigation and adaptation of global climate change. In line with the perspective that climate change problems should be collectively tackled, the U.S. government has adopted a policy of Joint Implementation.

The basic federal instrument to improve air quality standards is the Clean Air Act. The original Act was enacted in 1955 and has been substantially amended in 1970, 1977, and 1990. State programs under the Clean Air Act typically incorporate the following elements:

- inventorying of emission sources and monitoring of air quality for the purpose of planning pollution control strategies;
- issuance of permits to existing sources specifying permissible levels of emissions and, if reductions are necessary, dates by which reductions must be achieved;

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4 More information on these measures can be found in Enquete Commission (1995), Ireland Department of the Environment (1993), Italy Ministry of the Environment (1994), Sampson(1995), and Schnutenhaus (1995).

5 U.S. greenhouse gas emissions for 1990 were of the order of 1462 million metric tons of carbon equivalent (MMTCE) (Clinton & Gore, 1993)

- monitoring of sources' compliance via inspections, review of records, or sampling of emissions and fuels;
- enforcement action against non-complying sources; and review and permitting of proposed new sources of pollution (Liroff in Hansen & Roland, 1990).

Amendments to the Clean Air Act include a mandate to use emission trading and other economic incentives to curb pollution and CO_2 emissions. Revenue from emissions trading would be used to fund clean air programs and invest in infrastructure and pollution abatement technologies. The sale of cleaner gasolines is required in a clause which establishes the Oxygenated Fuel and Reformulated Gasoline Programs. Ethanol and methanol are listed as clean alternative fuels in the Clean Air Act and in the 1992 Energy Policy Act. Requirements of the Energy Policy Act (1992), the Alternative Motor Fuels Act (1988), the 1991 Executive Order 12759 - Federal Energy Management, and the 1993 Executive Order 12844 - Federal Use of Alternative Fuelled Vehicles, should also draw significant numbers of non-petroleum using vehicles into Federal, state, and private fleets by 2000.

A voluntary program for the reporting of information on greenhouse gas emissions and reductions, with the latter including forest management practices and tree planting has been established through the Energy Policy Act (1992). In this way U.S. policy is also encouraging industry to look to forests as one way of mitigating greenhouse gas emissions (Sampson, 1995). Tree planting is also encouraged, but not a mandatory part of the Conservation Reserve Program contained in the 1985 Farm Bill which requires the setting aside of some farm land under cultivation. The 1995 Farm Bill also contains the Conservation Reserve Program, however, the 1995 Farm Bill has not yet been ratified.

Under the Clean Air Act each state is to develop its own pollution abatement program in order to achieve ambient air standards. States have also been presented with increased administrative responsibilities and the need to make new investments in areas such as public transit in order to avoid cuts to their federal highway funds. An example of one such state program is the Minnesota ReLeaf Program. This is a tree planting program which is funded by a carbon content fee on fossil fuels. This essentially amounts to a carbon tax of 54¢ per ton of carbon. Further research by the Minnesota Pollution Agency found that while trees help to combat global climate change they do not necessarily result in lower energy use in Minnesota. In response to this finding, the Minnesota government introduced a bill in 1992 called the Sustainable Energy Transition Bill. This legislation proposes a $6 per ton carbon tax. Whereas the carbon content fee of 54c per ton of carbon is charged in order to fund the ReLeaf program, the $6 per ton carbon tax is intended to induce individuals to reduce the amount of energy which they consume. The revenues of this tax are to be used to support energy assistance and energy conservation programs for low income families, and for financing energy efficiency and renewable energy programs, and capital investments (Muller, 1993; Muller & Hoerner, 1993).

The Climate Change Action Plan (Clinton & Gore, 1993) draws the threads of policy and legislation together well. The Plan, if implemented correctly, will reach the target for greenhouse gas emissions through cost effective domestic actions. Such actions take the form of the Climate Challenge, the Climate Wise Programme, the Motor Challenge, Employer Paid Parking, The Biofuels Systems Program, the Biomass Power Program, a Green Lights effort, “Golden Carrot” Programs for industrial equipment, and the Partnership for a New Generation Vehicle Initiative. Most of these actions are supported by the policy objectives of collaboration between the private sector and the federal governments, and funding research and development.

Joint Implementation is viewed as a central part of the US’s international strategy to reduce greenhouse gas emissions. The U.S. Environmental Protection Agency (EPA), U.S. Agency for International Development and U.S. Department of Agriculture Forest Service have launched a co-operative effort called “Forests for the Future”. As part of this effort, carbon offset projects are being negotiated in a number of countries including Mexico, Russia, Guatemala, Indonesia and Papua New Guinea. The U.S. has already signed an agreement (in September 1994) with Costa Rica pledging their co-operation in reducing the threat of global climate change (U.S. Initiative on Joint Implementation, 1994). The agreement endorses the use of bilateral private sector partnerships to reduce greenhouse gas emissions. Canada and the U.S. also have an Air Quality Agreement. They have agreed to control transboundary air pollution between the two countries and to set up objectives for limiting emissions and reducing air pollutants. Most of these objectives apply to sulphur dioxide and nitrogen oxides. However, the Subcommittee on Air Quality has been given the task of integrating other air quality issues such as smog, particulate matter and climate change which includes carbon dioxide emissions (The Air Quality Committee, 1994).

Canada

Currently in Canada, CO_2 is the principal greenhouse gas (GHG) emitted, accounting for 87%, or 460Mt, of the total of all Canadian GHG emissions. (Environment Canada, 1994). It was estimated in 1990 that the total GHG generated by humans in Canada was equivalent to 526 megatonnes (Mt) of CO_2 emissions. However, these figures have been revised to take into account methane from landfills and livestock, and revisions to the global warming potentials for methane and nitrous oxide. The most recent estimate of total CO_2 equivalent emissions is now 577 Mt. “Based on this revision and changes estimated for projected energy-related emissions, forecasts indicate that total GHG emissions in the year 2000 will be in the range of 645 Mt, or about 13% higher than 1990 emission levels (Environment Canada, 1995a).” Table 1 presents 1990 figures for Canada’s greenhouse gas emissions broken down by sector.

Internationally, Canada has the second highest levels of CO_2 production per capita and per unit of GDP, second only to the United States of America. This is due, in part, to the production of energy intensive, internationally traded export commodities (gas, oil, minerals, forestry and agricultural) on which Canada's economy is based. Large distances between urban centres and a cold climate are also contributing factors in Canada's high levels of CO_2 production. Broken down by province, Canadian CO_2 emissions in 1990 were as follows:

- 32% Ontario
- 27% Alberta
- 13% Quebec
- 9% British Columbia
- 6% Saskatchewan
- 3% Manitoba
- 10% Other

(Canada's National Report on Climate Change, 1994)

A more detailed breakdown of provincial CO_2 emissions for each sector is in Table 2.

Table 1. Major Greenhouse Gas Emissions by Sector for Canada in 1990 (kilotonnes).

Source	CO_2	CH_4	CH_4 CO_2 Equiv.	N_2O	N_2O CO_2 Equiv.	Total CO_2 Equiv.	% of Total CO_2 Equiv.
Transportation Sources							
Automobiles	49,019	10	110	20	5,400	54,529	10.4%
Light-duty Gasoline Trucks	23,094	5	55	9	2,430	25,579	4.9%
Heavy-duty Gasoline Trucks	2,235	<1		<1		2,235	0.4%
Motorcycles	149	<1		<1		149	<0.1%
Other	7,292	1	11	1	270	7,573	1.4%
Light-duty Diesel Vehicles	136	<1		<1		136	<0.1%
Heavy-duty Diesel Vehicles	21,410	2	22	3	810	22,242	4.2%
Other Diesel Engines	14,363	1	11	2	540	14,914	2.8%
Air	13,137	1	11	1	270	13,418	2.5%
Rail	6,315	<1		1	270	6,585	1.3%
Marine	7,782	<1		1	270	8,052	1.5%
Subtotal- Mobile Fuel Sources	144,931	23	253	38	10,260	155,444	29.5%
Stationary Sources							
Electric Power Generation	93,873	1	11	2	540	94,424	17.9%
Industrial Fuel	75,350	3	33	2	540	75,923	14.4%
Residential Fuel	40,733	2	22	2	540	41,295	7.8%
Commercial Fuel	23,984	1	11	<1		23,995	4.6%
Other Fuel	52,667	<1		<1		52,667	10.0%
Fuel Wood		1	11	3	810	821	0.2%
Subtotal - Stationary Fuel Sources	286,607	8	88	9	2,430	289,125	54.9%
Industrial Processes							
Upstream Oil and Gas Production	7,567	1,100	12,100			19,667	3.7%
Natural Gas Distribution	?	18	198			198	<0.1%
Cement/Lime Production	7,666					7,666	1.5%
Non-energy Use	13,620					13,620	2.6%
Coal Mining		143	1,573			1,573	0.3%
Chemical Production	?	?	?	31	8,370	8,370	1.6%
Subtotal - Industrial Processes	28,856	1,261	13,871	31	8,370	51,097	9.7%
Incineration							
Wood Waste		1	11	?	?	11	<0.1%
Other		<1		?	?		<0.1%
Subtotal - Incineration	0	1	11			11	<0.1%
Agriculture							
Livestock/Manure		1,000	11,000			11,000	2.1%
Fertilizer Use				11	2,970	2,970	0.6%
Land Use Change	?	?	?				
Subtotal - Agriculture	0	1,000	11,000	11	2,970	13,970	2.7%
Miscellaneous							
Prescribed Burning		38	418	1	270	688	0.1%
Landfills		1,405	15,455			15,455	2.9%
Anaesthetics				2	540	540	0.1%
Subtotal - Miscellaneous	0	1,443	15,873	3	810	16,683	3.2%
National Total	460,394	3,736	41,096	92	24,840	526,330	100%
% of National Total	87%		8%		5%		

Source: Environment Canada in Canada's National Report on Climate Change (1994).

Table 2. Summary of Carbon Dioxide Emissions by Sector, Province and Territory in 1990 (kilotonnes).

Sector	Terr.	BC	Alta.	Sask.	Man.	Ont.	Que.	N.B.	NS	P.E.I	NFLD.	Total	%
Transportation	847	19,255	21,107	7,441	6,182	46,784	29,286	4,113	5,420	682	3,814	144,931	32%
Electric Power Generation	307	1,227	39,704	10,277	492	25,935	1,430	5,895	6,873	102	1,631	93,873	20%
Industrial Fuel	103	7,322	13,804	2,633	1,313	33,204	13,790	1,404	717	37	1,024	75,351	16%
Residential Fuel	144	3,986	6,411	2,064	1,606	16,452	6,092	943	1,986	354	694	40,732	9%
Commercial Fuel	146	2,825	4,850	960	1,398	8,398	3,876	563	590	130	247	23,983	5%
Other Fuel	339	4,370	26,708	4,646	957	9,115	3,029	1,283	1,013	62	1,145	52,667	11%
Industrial Processes	6	2,122	13,886	674	236	7,461	3,659	142	273	3	394	28,856	6%
Total	1,892	41,107	126,470	28,695	12,184	147,349	61,162	14,343	16,872	1,370	8,949	460,393	100%
% of Total	<1%	9%	27%	6%	3%	32%	13%	3%	4%	<1%	2%		

Source: Environment Canada in Canada's National Report on Climate Change (1994).

In 1988, oil was the largest source of CO_2 emissions, accounting for 55% of Canada's total human induced CO_2 emissions. The remaining human induced CO_2 emissions are split about equally between natural gas and coal. In Alberta, production, transportation and refining of gas and oil, and the petrochemical industry are major consumers of gas and oil as both fuel and feedstock. In Quebec and British Columbia, low-cost electricity generated hydrologically and through the use of biomass, including sawmill waste from the pulp and paper industry, reduce CO_2 emissions. Fossil fuels, largely coal, are used to generate essentially all the electricity in Saskatchewan and Alberta, and hence both provinces have large CO_2 emissions from this source. Manitoba has relatively low-cost, hydrologically-generated electricity available. All the prairie provinces have relatively severe winters and higher energy consumption in the winters for heating purposes.

Regional differences in CO_2 emissions generation across Canada mean that maintenance of the principle of interregional equity makes it difficult when developing policy to address the issue of CO_2 emissions.

In Canada, the federal and provincial governments agree that climate change and rising CO_2 levels are an issue of concern. This concern was recently echoed by the Intergovernmental Panel on Climate Change (IPCC) in 1995 when they wrote that "global mean temperature changes over the last century are unlikely to be entirely due to natural causes, and that a pattern of climate response to human activities is identifiable in observed climate records." However, there is no agreement on just what the consequences of climate change will be, in particular, prediction of rates and regional distributions of climate change.

The National Action Program on Climate Change (NAPCC) is Canada's most recent plan to address climate change. It is an update to Canada's National Report on Climate Change released in 1994. In a consensus of federal, provincial and territorial governments, it sets out the principles, strategic directions and opportunity areas that Canada will follow to reduce GHG emissions. There are three components to address climate change. The first component is a variety of policy measures to reduce net emissions. The second is to research the connections between climate change and GHG. The third component within the NAPCC is to study the risks to Canada from climate change and how Canada might adapt. The NAPCC is scheduled for review in December 1996.

One of the key elements under Canada's NAPCC is the Climate Change Voluntary Challenge and Registry Program (VCR). Under this VCR Program, Canadian organizations, especially those in the industrial, commercial, and governmental sectors, are asked to voluntarily take actions to limit or reduce net GHG emissions. Each organization's commitments, action plans, progress and achievements are then publicly documented. Under the VCR Program, organizations are asked to provide information on net emission reductions planned. Actions such as energy efficiency improvement projects, fuel switching, or directly reducing emissions are encouraged. One of the main reporting categories in the VCR Program is that of offsets. Initiatives that organizations take to enhance a carbon sink or to sequester greenhouse gases either through plants or soils, domestically or internationally, are encouraged. Success of the VCR program relies entirely on corporations and organizations to accept the challenge and devise action plans to reduce net emissions.

Industry does not want GHG emission reductions to be driven by government imposed regulations, taxation, or legislation. Instead, companies and organizations have asked for an opportunity to deal with emission reductions in a cost-effective way. The VCR Program is seen as a way for industry to deliver in the manner that best suits their particular production and needs. This is a flexible program compared to carbon taxes, emission caps, and other programs that might be imposed if industry doesn't comply with the intent of the VCR.

Proponents of voluntary measures say business and governments have an opportunity to maintain economic growth while making innovative, cost-effective and measurable reductions in GHG emissions. Such an approach recognizes that Canada's international competitive position needs to be retained to meet domestic economic goals while scientific knowledge is being improved. However, those critical of the National Action Program fear that without specific commitments to take action, supported by fiscal policy instruments and minimum requirements set by regulation, no real progress on reducing emissions will be made. Government contends that the balanced approach offered through the use of voluntary measures allows the most cost effective means to reduce net GHG.

Provinces which wish to implement regulations or fiscal measures to regulate CO_2 emissions may do so (CASA, 1995). The federal government has authorized marketable permits[6] as an economic instrument, however, no jurisdiction has implemented marketable permits for CO_2 yet. There is concern that using economic instruments for reducing carbon emissions will have equity implications. While government imposed economic instruments such as marketable permits or a carbon tax offer cost-effective options of stabilizing or reducing CO_2 emissions, they can often involve large transfers of income. Other legislation forcing reductions in CO_2 emissions would require an unprecedented level of government intrusion into the economy and the decisions of private firms and consumers (Nichols & Harrison, 1991). Voluntary reductions and mitigating efforts avoid these problems and is the way the federal government has chosen to reduce CO_2 emissions.

The NAPCC states that, "Canada will actively exploit opportunities to reduce greenhouse gas emissions and enhance carbon sinks in agriculture and forestry." According to the NAPCC, appropriate actions to enhance and maintain the carbon sink capacity of Canada's forests include increasing afforestation and establishing permanent plant coverage with native grasses on marginal agricultural lands. Promotion of tree planting in urban and rural settings is suggested as a measure that could make an important

[6] A government creates marketable permits for carbon by issuing x permits that allow y tonnes of carbon to be emitted. In order to emit carbon it is then regulated that the producer has to have (a) permit(s). This creates a market where producers can buy and sell permits. Usually any amount of carbon emitted above the levels permitted is subject to a fine

contribution to enhance carbon sinks, though the NAPCC does not attach any numbers to this suggestion. Changing agricultural practices in order to decrease other environmental problems such as soil erosion is highlighted as an opportunity to reduce GHG emission and as well as a way to improve carbon sinks. Reducing summer fallow acreage, improving tillage practices, and making greater use of crop residues are recommended as improved agricultural practices.

A principal piece of federal legislation in Canada dealing with environmental protection is the Canadian Environmental Protection Act (CEPA). Initially developed in the mid 1980s and proclaimed in 1988, it is currently being redrafted. A standing committee reviewed CEPA, and in December 1995 the government released a comprehensive Government Response to the Standing Committee review of CEPA. Canada has also established the Canadian Climate Research Network (CCRN) to address critical scientific questions related to climate change and climate variability. The CCRN stresses global climate models and is not action oriented.

The federal government released Canada's Green Plan in 1990. The Green Plan set forth a national objective to provide a safe and healthy environment and a sound and prosperous economy for current and future generations. To meet this objective, the Green Plan was to provide policy and direction for GHG emissions. There were several Green Plan initiatives that related to clean air, one of them being the stabilization of CO_2 emissions and other GHG emissions at 1990 levels by the year 2000. Under the Green Plan, a process of voluntary commitment by industry to reduce the production of CO_2 emissions was put forth. The Green Plan also recommended that 325 million trees or 325,000 ha of forest be planted to combat rising CO_2 levels.

The Green Plan has recently been sunsetted as a result of the change in government. Programs that were created under the Plan may still be in existence but are being phased out. Under the Green Plan, initiatives such as Environmental Partners looked after community funding, and environmental citizenship programs. Tree planting activities formed a part of the environmental citizenship programs. With the demise of the Green Plan, Action 21 was launched by Environment Canada in September 1995 to respond to the federal government's commitment to communicate the individual and collective actions needed for sustainable development. Action 21 is not legislated but it will take over the role of the Environmental Partners initiative. Under Action 21, the Community Funding Program provides financial support to non-profit, non-governmental groups to undertake environmental projects in their communities. Projects must protect, conserve, rehabilitate or enhance the natural environment and/or lead to the practice of environmentally responsible behaviours. Under this program, projects that address the issues of air, ecosystems and natural diversity are encouraged. Ten million dollars per year have been slated for Action 21. While the programs under Action 21 are just in the start up phase, there appears to be many opportunities for tree planting activities to receive funding.

The National Community Tree Foundation, now the Tree Canada Foundation (TCF) was established in 1992 as an initiative of the Green Plan. The Foundation's mandate is to administer and promote the Tree Plan Canada program over a six year period. The TCF provides education, resources, and financial contributions through partnerships to encourage Canadians to plant, care for and maintain trees in urban and rural Canada. Over a four year period, ending March 31, 1996, the TCF has been involved in the planting of some 52 million trees (personal communication Depper)[7]. In accomplishing this feat, the Foundation worked with the Canadian Forest Services and in partnership with organizations such as Global ReLeaf, Earth Day Canada, and the Evergreen Foundation. TCF continues the Green Streets Canada program which expands urban forestry action through involving local communities in tree planting. As well, TCF provides technical assistance and endorsement for companies who wish to contribute to tree planting through sponsorship programs. If carbon credits were to be offered in Canada for tree planting programs, the Tree Canada Foundation would be well suited as a mechanism to oversee such a venture.

There has been much talk of more regulations and incentives such as rebate schemes to help reduce CO_2 emissions. Various reports look into the feasibility of such actions. The DRI/Marbek Resources report (1993) *Canadian Competitiveness and the Control of Greenhouse Gas Emissions* and Alberta Energy/Environment/CAPP report (1991) *Market-based Approaches to Managing Air Emissions in Alberta*, are two such reports. The latter of these two finds that economic instruments such as tradable carbon coupons or a carbon tax are cost effective options for Canada as it strives to reduce CO_2 emissions.

In the COGGER Report (1993) various studies, both in Canada and internationally were evaluated, and it was determined that Canada not only has the ability to reduce emission levels to 1990 levels, but that to do so would be economically feasible. It was concluded that reducing CO_2 emissions is something Canada should do even without taking global warming into consideration.

The fact that reported industry actions to reduce emissions are currently not enough is discussed in the COGGER Report. No companies are taking sufficient steps to allow Canada to meet its stated goals, and no companies are going the extra mile and putting plans into place to allow them to further reduce emissions. COGGER strongly states that policy measures are necessary. However, no legislation or policies are forthcoming. Even the hint of impending steps by the government is enough to arouse industry leaders. Industries such as the Coal Association of Canada support voluntary measures "embracing cost effective, practical actions that have the additional merit of reducing the rate of emissions. New or increased regulation and taxation are not justified" (Coal Association of Canada, 1994).

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7 Tree seedlings planted though the Tree Canada Foundation programs are obtained from public and private nurseries in the area. In the prairie region this would include PFRA tree nursery, the provincial government tree nurseries, as well as private tree nurseries.

Companies and organizations are making changes and these changes have led to reductions such as those reported by organizations such as the Canadian Chemical Producers' Association (CCPA). The CCPA reports reductions of about one million tonnes of carbon dioxide in 1993, a reduction of 8% over 1992. They are projecting continued decreases in CO_2 emissions by 1998. The reduction of GHG emissions are due to energy efficiency improvements made throughout the 1970s and 1980s. However, they state: "Since the chemical industry is energy intensive, emissions of carbon dioxide are related to the rate of production. As the economy grows over the longer term, members will find it increasingly difficult to achieve the goal of stabilizing carbon dioxide emissions due to the challenge of further reducing the amount of energy used per tonne of product (CCPA, 1993)". This is not to say that industry will lessen efforts to achieve further emission reductions. Rather, they expect to continue to work towards this and search for alternatives to some substances and to develop more efficient manufacturing methods. These sentiments are echoed by other Canadian gas and oil producers.

Canada's National Report on Climate Change (1994) predicts an increase in emissions of GHG by 2000 over 1990. The report concludes that additional measures will be needed if Canada is to meet its climate change objectives. Actions to do so are already under way as can be seen by what some of the provinces are doing, however, they are not sufficient.

Practices

Alberta has led the way in setting action plans for air quality. Due to the province's heavy reliance on natural gas and oil production, air quality has long been a concern. In 1990, the Government of Alberta initiated a public consultation process called the "Clean Air Strategy for Alberta". That process acted as a catalyst for discussion on air quality issues, and helped to define the most pressing problems in Alberta and decide how best to control them (Alberta Government, 1990). A recommendation that came out of this consultation was the need for a multistakeholder group to implement a new air quality management system. To meet this recommendation, in 1994 the Clean Air Strategic Alliance (CASA) was formed. CASA has put forth a number of recommendations for Alberta's participation in the national climate change process which is the basis for the Alberta Action Plan and for the Alberta position in the national climate change discussions. The Alliance has adopted a sustainable development approach to air quality matters and to achieve this manages air quality issues and makes public policy using multi-stakeholder consultation and consensus decision-making (CASA , 1995; Alberta Government, 1990).

CASA has formed a carbon sequestration opportunities working group to identify opportunities to enhance Alberta's contribution to Canada's stabilization undertaking through sequestration and storage of carbon in prairie soils and boreal forest ecosystems. They have, through the Alberta Government, encouraged the governments of Saskatchewan, Manitoba and Canada to include the potential contribution through prairie soils in their action plans.

Various energy efficiency programs are in place to reduce energy consumption across the country. One example is the Twenty Percent Club, in which at least eight Canadian cities, each with their own plan, pledge to reduce GHG emissions by one-fifth by 2005 from 1988 levels. The eight cities (Edmonton, Metro Toronto, Montreal, Ottawa, Regina, Toronto, Vancouver, and Victoria) are sharing ideas in a joint effort to combat global warming. Main activities include retrofitting city buildings, introducing energy saving measures for the cities' fleet of vehicles, and planting of trees. In addition to the environmental benefits, positive spin-offs of these activities are jobs and estimated energy savings in future years.

The Federal Government considers ethanol to be an alternative fuel and does not levy the fuel excise tax on ethanol, or the ethanol portion of ethanol blended gasoline. Provincial governments are free to do as they will with taxing of ethanol. Currently in Manitoba ethanol blended gasoline is taxed at 2.4¢/L less than regular gasoline. Saskatchewan removed the subsidy that had been allocated to ethanol blended fuels in 1995 and now, as in Alberta, the ethanol portion of the gasoline is not taxed. These tax breaks do not translate into savings at the pump as ethanol is presently more than twice the price of conventional fuel. Bruce Hodgins, Mohawk Oil Co. Ltd. (personal communication, March 14, 1996) states that remaining ethanol subsidies and tax breaks are being reviewed and may disappear in the next few years as provincial governments continue to tighten their budgets.

In British Columbia, BC Hydro can apply a premium to electricity derived from environmentally acceptable sources. Regional Districts in British Columbia, for example the Capital Regional District, have developed recommendations for all levels of government to address atmospheric change. Measures to reduce GHG and to increase and protect carbon sinks, coupled with emission regulations have shown commitment by the provincial government to take action rising GHG levels. Ontario has a mid-efficiency gas furnace standard, and various provinces have vehicle inspection and maintenance programs. Under the Green Plan*,* the federal government specified some policies, such as minimum appliance efficiency standards and expansion of the R-2000 program.

The programs mentioned above encourage reductions in CO_2 emissions. There are also programs which encourage actions that enhance carbon sequestration. The government recognizes that there are two ways in which humans can do this: changing land management practices and planting trees.

CO_2, methane and nitrous oxide emissions related to agricultural activities, such as manure and fertilizers (represented on a CO_2 equivalent basis) account for approximately 5% of Canada's greenhouse gas emissions. Agricultural production is also a large consumer of fossil fuels to power farm equipment and vehicles. One program that may be eliminated in the future is the fuel rebate for fuel used for agricultural production. Such a program does little to encourage reduction of fossil fuels, which goes against the NAPCC. If the program is not eliminated, perhaps it will be modified to encourage use of biofuels.

Given agriculture's contribution to rising CO_2 levels, it would make sense to apply policy and action in this sector too.

To encourage the transfer of land out of production and into a protected, preserved, conserved, or natural state, there are tax exemptions for land owners. These exemptions fall under Canada's Permanent Cover Program. Such changes can reduce the amount of carbon loss associated with agricultural operations, and improve soil organic matter and sink capacity of the soil. Agricultural soils will either be a source or sink for carbon depending on the quantity and quality of soil organic matter and the management practices used. Interactions among agricultural practices, climate, and retained carbon are extremely complex (NAPCC, 1995). Since it is not possible to control the effect of climate on soil organic matter, attention must be focused on adjusting agricultural practices.

Agriculture is fundamental to current human existence and cannot be terminated as an activity. However, by changing agricultural practices it is possible to decrease carbon emissions and prevent further carbon losses. Changing farming practices can include reduction and elimination of tillage, direct seeding, and decreased summer fallow all of which lead to less cultivation and therefore less fuel burned. Continuous cropping, permanent forages, the use of forages in crop rotations, and trees planted in shelterbelts or in woodlots all represent storage sites for carbon. Continuous cropping and reduced tillage systems increase soil organic matter which is another major site of carbon retention. Better tire performance, gear selection, and tractor sizing also help improve fuel efficiency and reduce emissions. Decreased usage of fossil fuels and increased production of renewable fuels such as ethanol will also decrease the net CO_2 emissions generated by the agricultural producer. Production of nitrogen fertilizer used in agriculture is another major source of carbon emissions. Therefore, substitution of animal manures and legumes for commercial nitrogen fertilizers would lessen the consumption of fossil fuels.(CASA, 1995). Many of these practices are already being incorporated in Canada for economic and environmental reasons.

If farm practices are changed and if there is a reduction in ruminant animal methane emissions and improvements in livestock manure efficiency, it is estimated GHG emissions can be reduced by 14 million tonnes of CO_2 equivalent (3.7 million tonnes of carbon) by the year 2000 relative to 1990 (National Agriculture Environment Committee, 1994). These projected carbon reductions are presented below in Table 3. The figures of 3.7 and 5.6 million tonnes of carbon translate into 14 and 20 million tonnes of CO_2 respectively. When compared to total estimates of Canadian emissions of CO_2 equivalent for 1990 this represents 2.7% and 3.8% of emissions related to human activities.

In addition to changing farming practices, tree planting is seen as a relatively low-cost solution to sequester carbon with multiple benefits. Tree planting helps offset deforestation, expands carbon sinks, and trees can be used in the production of biofuels.

Table 3. Projected Reductions in Net GHG Emissions.

	1990-2000	1990-2005
	- - millions of tonnes of carbon/year - -	
Reduced summer-fallow	0.2	0.2
Adoption of no-tillage	1.0	1.6
More forages	0.9	1.2
Higher yields	0.9	1.4
Ruminant animals	0.1	0.2
Livestock manure	NE	NE
Nitrogen fertilizer	NE	NE
Fossil fuel usage	0.5	0.7
Ethanol-blended gasoline	0.1	0.3
Photosynthetic "feed-back"	NE	NE
TOTAL ESTIMATE	3.7	5.6

NE - Not estimated
Source: National Agriculture Environment Committee (1994).

The rate at which CO_2 is sequestered by trees depends on the species of trees planted, soil, water and weather conditions, age of trees, as well as the location of their planting. The OECD (1991) provides an average carbon sequestration rate of 2 tonnes of carbon/hectare-year on average for tree plantations in temperate climates. This figure is somewhat higher than the sequestration rate that is expected in urban areas. However, this rate is considered conservative as it does not take into account the carbon added to the soil pool by leaves and branches falling from the trees (Stewart, 1992 in DRI & Marbek, 1993).

There are conflicting opinions on whether planting trees will help Canada reach its short-term 2000 target. A study prepared for the Canadian government by DRI and Marbek (1993) states that: "Planting more trees than the 325 million called for in the Green Plan over the simulation period could not take up significant additional amounts of carbon by 2000 or even 2010." They assumed that it would take trees fifteen years to reach the average sequestration rate of 2 tonnes/hectare/year. Their calculations suggest that approximately 230,000 tonnes/year of carbon, or 851 kilotonnes/year of CO_2, would be sequestered after 10 years. After 20 years approximately 650,000 tonnes/year of carbon or 2,383 kilotonnes/year of CO_2 would be sequestered (DRI & Marbek, 1993). Planning for short-term goals, however, does not take care of sustainability issues such as intergenerational equity[8]. In the longer term trees do have the potential to offset significant amounts of carbon dioxide.

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[8] Intergenerational equity refers to consideration of future generations in the allocation, distribution and use of resources.

The Prairie Farm Rehabilitation Administration (PFRA) has been carrying out research on tree and shrubs in the prairies, and providing tree and shrub seedlings, along with technical expertise on planning, planting, and maintaining trees and shelterbelts in the prairie provinces since 1935. More recently, PFRA has been conducting research on biomass production on the prairies. Estimates on biomass and the amount of carbon in caragana, green ash, Manitoba maple, hybrid poplar and Siberian elm are given in Appendix A (Kort & Ashford 1994; Kort, 1996). The Tree Canada Foundation has tabulated carbon data for the prairie provinces looking at various species of trees, site type, and age of trees and calculating biomass and total carbon fixed by the trees (Tree Canada Foundation, 1995). This information is available in tables in Appendix B, C, and D of this report.

Tree planting initiatives can fall under a number of categories. Reforestation takes place in commercial forests which are managed primarily for harvesting and regeneration of wood for use in the timber, or pulp and paper industry. Reforestation or afforestation can create woodlots in rural areas where land is currently used for crops, pasture, or which is of marginal value. Planting of trees to form shelterbelts, living fences or for aesthetic purposes adds trees to an area without drastically changing the use of the land. Trees can also be planted, or protected, to create urban forests. Urban forests consist of trees growing in the vicinity of homes and other buildings in places where the dominant land use is urban or suburban areas.

On the prairies, corporations and organizations have initiated tree planting projects outside of those aided by the Tree Canada Foundation. TransAlta Utilities Corporation in Alberta has been very proactive in its tree planting efforts and research on carbon fixing. In Saskatchewan, SaskPower operates a greenhouse, heated by wasted heat generated at its Shand Power Station, which produces about 300,000 seedlings each year for reforestation projects (SaskPower, 1995)[9]. An association of western Canadian electrical and gas and oil companies is in the process of forming the Greenhouse Gas Emissions Management Consortium (GEMCo.) GEMCo aims to demonstrate industry leadership in developing voluntary and low cost opportunities for GHG emission management. Energy producing companies seem to be interested in planting trees as part of their overall environmental program. Tree planting does not appear to be seen as an economically viable undertaking for corporations if the purpose is strictly for carbon fixing. If increased CO_2 sequestration is one of a number of benefits (i.e. local economic development, and community benefits) then corporations are more likely to become involved in reforestation and afforestation projects. This interest could also be due to the high visibility of tree planting, and more importantly, that this activity may delay the imposition of government regulations.

[9] These reforestation projects were originally intended for reclaiming land that had been mined. However, SaskPower is now recognizing the carbon sink potential of these trees as well.

Ownership rights to trees planted under initiatives to offset CO_2 emissions could become a contentious issue. Rheaume (1993) cites an example of an oil company investing in afforestation done by a logging company on provincial land. Who owns and is responsible for the trees; and then who decides if, and/or when they are harvested (reducing the offsetting effect in the process); are all questions with no easy answers. Rules of conduct in the use of offsets need to be established in cases such as the one just described, or in variations of this scenario, such as international reforestation.

Feasibility of Tree Planting as an Action

To assess whether it is feasible to reduce carbon dioxide emissions through plant biomass increase, a couple of things need to be taken into account. First of all, it would be logical to use plant species that fix the most carbon or have the greatest potential for photosynthesis. The rate at which CO_2 is sequestered depends on the species planted as well as the location of their planting, soil type, and weather. Not all plants are suitable for all environments, so they need to be selected first on the basis of whether they will grow in the environment in question. Trees and shrubs that grow well in the prairies must be able to deal with the limited water and harsh winters. Caragana is the most widely distributed shelterbelt species on the prairies because it is so hardy and adapted to the conditions. However, fruit bearing trees and shrubs such as the buffaloberry, choke cherry, and Saskatoon also grow well.

Furthermore, when considering how much carbon can be fixed, it is not only important to look at how much is accumulated in the biomass but also at what the turnover rate of carbon is in the cycle. Agricultural plant biomass stores less than 10% the carbon that trees do, but Naeth (1990) in reviewing the published literature has found that the turnover rate for non-woody species is much higher than for tree species. She also found that the amount of below-ground biomass, which contributes significantly more to carbon sinks, is higher in non-woody plants. Thus, temperate grasses and legumes have great potential to enhance the amount of carbon being stored as soil organic matter. Planting herbaceous species such as grasses, vegetables, and cereal crops can be just as effective as planting trees in reducing atmospheric CO_2. In this paper, however, we look at the feasibility of planting trees only. In examining the feasibility of adopting such an action it is necessary to look at both the benefits and the costs of doing so.

Trees are net sources or sinks for carbon depending upon net changes in biomass. More carbon is absorbed than released only when incremental growth exceeds incremental decay. Investment in afforestation programs and encouraging various forest management activities designed to promote tree growth as a method to mitigate global warming is seen as a temporary and limited solution as trees absorb carbon only as long as they are growing.

Benefits

Many of the actions that can be taken to reduce climate change have other benefits. For example, conserving energy saves money and also helps reduce problems such as acid rain and smog. Forests and trees, because of their carbon storage capacity, present an important opportunity for CO_2 emission mitigation. In addition to fixing carbon, trees offer a myriad of additional socio-economic benefits such as erosion control and conservation of soil and water, aesthetics, wildlife habitats, conservation of biodiversity, watershed protection, pollution control, and reduction in temperatures. Some of the environmental, economic and social benefits of trees bear further discussion.

Environmental

Trees contribute to the health of the environment both within Canada and around the world. They help to regulate atmospheric conditions and moderate the effects of external forces on soil and water. Trees protect the soil by sheltering it from strong water flow and from wind. Tree roots absorb water and nutrients from the soil. Leaves fix carbon dioxide from the atmosphere, returning oxygen as a by-product. The carbon is fixed in the biomass and soil during the process and stored for years. The functional value provided by these benefits is difficult to quantify, however.

Ecological functions that trees perform, such as hydrological and carbon cycling, regulation of watersheds, and protection of soil are very important to the ecosystem and as a result, communities within the system. The following is a list of some of the more important environmental effects of trees:

- improve soil health; increase soil organic matter
- reduce wind and soil erosion; protect soil, crops, livestock, homes
- increase moisture
- wildlife and biodiversity aspects, both positive and negative
- purify air
- assist in snow trapping for dams/dugouts
- improve watershed and groundwater conditions
- carbon fixing
- climate regulation

Whether soil organic matter will be enhanced may depend on the status of the soil at the time of planting. Soils under brush or pasture may be at or near normal SOM levels.

Anielski (1991) estimated the service value of Alberta forests and peatlands in the fixation of carbon from CO_2 emissions. These estimates show that Alberta's forests sequester roughly 24% of Alberta's total CO_2 emissions and that forest peatlands sequestered an additional 3%. The conservative value of the benefit of the carbon sequestering in 1990 was $186 million dollars with an upper value given as $2.79 billion. This conservative estimate translates roughly into 23% of forestry GDP ($807 million) in 1990 (Anielski, 1991). When looking at these estimates it must be noted that because of problems with measuring emissions and removal of CO_2 emissions by organic matter, it is not possible to reach definite conclusions.

Economic

Beyond the environmental benefits of trees, there are a variety of economic spin-offs from planting trees to sequester carbon. To begin with, economists have attempted to estimate the value of carbon and the economic welfare losses due to GHG emissions to determine a shadow price for CO_2. Estimates of the value of carbon vary depending on assumptions concerning the rate of technical change, the rate of growth of the economy, the discount rate, levels of damage from CO_2 emissions, and the percentage reduction in CO_2 emissions. The value for carbon for a 20% reduction from 1990 levels has variously been calculated at between US$11 and $275 per tonne. At a reduction rate of 50% from 1990 levels, the value of carbon has been calculated at $132 per tonne (Nordhaus in Van Kooten, 1992). Nordhaus (in Van Kooten, 1992) has also assessed that the best estimate for marginal damages from carbon emissions is $14 per tonne. These values may become significant if a market for carbon emissions credits is set up.

A more direct economic benefit of trees is that they provide an opportunity for landowners to diversify and stabilize incomes. With recent changes in technology, what was once considered waste wood can now also be utilized for fibre. This coupled with pressure on public forests by recreational users, environmental groups and others, many forest products firms have been considering alternative sources of fibre. Trees in woodlots are receiving high prices from BC sawmills for pulp and paper production. Land owners in Alberta were getting $45 to $50 a cubic metre in 1994, while Saskatchewan woodlot owners were receiving $25 to $29 a cubic metre for softwoods. Rampant harvesting of these private wood supplies is now coming under regulation in order to meet environmental standards. This will affect how much private land is harvested and when, thereby limiting the regularity with which harvesting can take place, but raising the price of timber due to scarcity value. High prices for timber such as these could work as a strong motivator for farmers to adopt tree planting practices (Nikiforuk, 1995). However, while woodlots on the prairies may be one way for land owners to diversify, a 1995 report suggests that hybrid aspen plantations may not be financially feasible on private land (Salkie & White, 1995).

Lumber from prairie trees can also be used for rough construction, used by artisans, or sold for fuelwood. PFRA has assessed the lumber potential of Manitoba shelterbelts and found that the average value of lumber for a half mile shelterbelt was $3,465 based on lumber values of $462/thousand board feet for ash and $400/thousand board feet for elm. Wood from prairie trees can also be sold as firewood (PFRA, 1993).

Harvestable produce from trees offers another source of income to land owners. Soft fruits such as Saskatoon berries and choke cherries are becoming more and more popular. Fruit trees require a lot of water and maintenance and this may be an inhibiting factor if farmers were to plant them in their shelterbelts. PFRA is now also looking into the production of maple syrup from native Manitoba maples.

Conservation benefits of trees offer economic savings too. Increased soil organic matter results in reduced fertilizer costs and higher crop yields. Energy is conserved through shading and windbreak effects on buildings which means lower heating and cooling bills as well. In a study looking at shelterbelts in Saskatchewan determined that while heat loss reduction varied with the density of the shelter and the velocity of the wind with the reduction realized between 17.5 - 25% (Moyer, 1990). These values were considered conservative. Other studies have looked at urban tree planting and found that cooling savings from a well-placed trees can be in the 10 - 43% range. This cooling results both from shade from the tree and lower air temperatures from evapotranspirational cooling (McPherson, 1994).

Social

While the main benefits of planting trees in the prairies are environmental and economic, there are also social benefits realized through tree planting. Social benefits of trees are difficult to quantify. For instance, there is an existence value of trees which people receive just by knowing that they exist.

The primary social benefit of trees is the aesthetic value they provide. Trees are considered to be beautiful and to add the landscape. They provide habitat to wildlife and in so doing add to amenity and recreational values, particularly for birdwatchers and hunters. Wooded areas also offer the possibility of nature education for children. Trees perform a security function too. They are a shelter against the elements in general and roadside shelterbelts can be used to control snow drifting.

Trees help to reduce winds, control dust, and absorb air emissions resulting in cleaner air, which is a social benefit in terms of human health. Shade and cooling benefits provided by trees can also have positive health impacts during the hot season.

Costs and Cost Mitigation of Tree Planting

Costs associated with tree planting programs need to be examined from three perspectives: the cost of not adopting any measures to reduce or counteract CO_2 emissions; the direct cost incurred in adopting a tree planting programme; and the cost of using land for trees rather than some other purpose like crops or pasture. From the viewpoint of sustainability it is also important to consider not only the pecuniary costs, but also the social and environmental costs of these actions. Ways of recovering cost is also something to be considered because in the balance of things this will make certain actions more viable.

The Cost of Inaction

Intensification of the greenhouse effect is thought to cause global warming and climate change. To date no actual effects of this process have been convincingly demonstrated, but it is reasonable to suppose that important environmental consequences will result from an intensification of this warming function. These effects could be more frequent and climate extremes; disruptions to agriculture; extinction of some species of animals and plants; increased disease and pest infestations; rising sea levels; changes in water quality; and economic consequences (Freedman & Keith, 1995). Changing climate may have a detrimental effect on agriculture as well. The more productive lands of the southern prairies are projected to experience more frequent droughts and reduced yields which could be accompanied by a new wave of human resettlement. In the north, warmer temperatures will expand the growing season and may increase yields. The potential also exists for expanding agriculture further north. However, a limiting factor will be a lack of suitable soils.

Assuming the climate is changing as predicted by the various climate change models, coping with increased drought, forest fires and severe storms would cost Canadians billions of dollars. Less would be spent on heating but this would be balanced by the air conditioning bill. Shorter winters and longer summers would change the recreational choices that people make, at the same time threatening some people's livelihoods and improving other's. Municipal taxpayers would pay more or less for snow removal services depending on where they live and the shipping season would be ice-free for longer. Individuals and insurance companies alike will have to bear the costs of coping with a changing climate (Environment Canada, 1995b).

An actual pecuniary cost has not yet been calculated for these possibilities. It is, however, prudent to consider strategies to avoid the potentially devastating consequences of global warming and climate change. It is from this perspective that tree planting on the prairies is considered as a method for offsetting harmful carbon emissions.

Direct Costs

Direct costs of tree planting include the cost of site preparation, the cost of seedlings, the cost of planting the trees and the cost of maintaining them once they have been established. Maintenance consists of weed and pest control, and tillage. PFRA (undated) estimates the costs of maintaining shelterbelts at Cdn $31/km (these costs do not include pruning or watering). Direct cost for planting trees in Saskatchewan has tentatively been estimated at $1,215 per ha.

In determining whether it is viable to plant trees for sequestering carbon it is necessary to know how much it cost per tonne of carbon fixed. The cost of planting trees per tonne of carbon fixed for both urban and rural forests has been calculated. The cost per tonne of carbon fixed in Saskatchewan would then range between $9.14 (assuming 133 tonnes of carbon fixed) and $37.04 (for 32.8 tonnes of carbon fixed) depending on the type of tree/forest and soil type. Typically, urban forests cost more than rural forests due to the fact that trees are larger when planted and have higher maintenance costs in the early post-planting years. Estimates for planting urban trees have been calculated at U.S. $15-30 per tonne of carbon fixed compared to U.S. $1-10 per tonne carbon fixed for rural trees[10]. However, the benefits of energy saving through strategic planting of urban trees

[10] Other studies (in North America) have estimated the cost of establishing rural trees for carbon sequestration by calculating the cost of establishing trees plus the opportunity cost as agricultural commodities are displaced by trees. The estimates for sequestering 39 million tonnes of carbon per year range from U.S. $13.52 per tonne to U.S. $18.22 per tonne of carbon (McCarl & MacCallaway, 1995).

have not been figured into the calculation. A study in Chicago showed that urban trees offset 2-10 times more carbon in energy savings than was sequestered by the growing trees (McCarl & MacCallaway, 1995; Freedman & Keith, 1995). The ratio of carbon reduction through energy saving to carbon sequestered through the planting of trees, however, will vary depending on whether fossil fuel inputs are used to generate energy or not.

Opportunity Costs

Planting trees on a large scale, particularly in the rural areas, means forfeiting other activities which could take place on that land. The cost of forfeiting one activity for another is known as the opportunity cost. Most commonly, planting trees on rural lands will reduce the land available for planting crops which will involve reduced income due to smaller yields. Trees could be planted on what was formerly pasture as well. Farmers could benefit from this new activity as the trees provide shelter from the wind in winter and sun in the summer. If the trees planted are harvested for commercial gain this will also affect the price of timber when done on a large enough scale. Furthermore, some farmers are reluctant to plant trees because they limit their flexibility in using the land in future years (Sampson, 1995). Other factors which inhibit farmers from planting trees are: increasing numbers of birds and wildlife which threaten crops; decreased yields due to land loss; time spent on maintaining trees which could be otherwise spent; increasing wear and tear on equipment due to turning in smaller areas; competition of trees for limited water; sometimes trees trap too much moisture at the end of winter and delay seeding.

Agricultural activities also have the potential to sequester carbon. Crops and pasture store carbon through photosynthesis and increasing soil organic matter. By changing agricultural practices this potential can be further enhanced. No till practices, reducing summer fallow, and permanent pasture contribute to increased soil carbon. The level of soil carbon will increase as these improved farming practices are adopted. However, the level of soil carbon will only increase up to an equilibrium point which is dependent upon various characteristics of the soil. Once this level of soil carbon has been reached, no further net carbon increases will be achieved. In this sense trees have a greater long-term potential for sequestering carbon since they fix carbon for as long as their biomass is increasing.

Cost Recovery Schemes

Some of the costs of adopting tree planting on the prairies could be recovered. Trees have multiple uses beyond that of carbon fixing. Soil erosion is decreased by trees planted as windbreaks and shelterbelts which also protect soil organic matter. As an economic saving, they reduce the amount of fertilizer needed and produce energy savings which can be used to offset costs. Urban forests can also result in significant energy savings through shading of buildings in summer and reducing the cooling effect of windspeeds in winter. Trees, as shelterbelts and as woodlots, also have the potential to be harvested for energy production, be that for replacing coal, oil or natural gas in electric power stations; or producing ethanol - a biofuel (Freedman & Keith, 1995; Sampson, 1995). The rationale behind such actions is that biomass energy and biofuels emit less carbon than the burning of fossil fuels. Furthermore, no net CO_2 emissions are released during burning since CO_2 emitted is reabsorbed by growing crops.

High-energy crops such as alfalfa and switch grass, and short rotation forestry systems, like hybrid poplar and willow trees, are used for generating biomass energy. If trees in shelterbelts and woodlots are to be used for generating energy, then attention needs to be paid to the types of trees planted in these settings. Trees need to be fast growing and harvested in 5- to 15-year cycles to be economically viable as a source of biomass energy. Growing poplars and hybrid poplars on the prairies may meet these requirements, although it would appear that poplars are harvestable in 15- to 20-year cycles. However, poplars are sparsely branched and once they lose their leaves in the fall, offer very little protection from the wind. Their shallow root system also makes them competitive with crops and gardens for water. Thus many of the other benefits from planting trees are lost by planting poplars in shelterbelts. If poplars were planted on the outside of farmyard shelterbelts or in woodlots they would be more viable for biomass energy and as a carbon sink (PFRA, 1992).

Thus far, most experience in biomass energy generation has not involved tree crops. However, scientists are of the opinion that trees are the best way forward since they do not suppress world food prices and are cheaper to use for this purpose than food crops. Most of the emphasis in studies being conducted in the U.S. and Canada is now on developing fast-growing trees and grasses as energy crops (US.DOE, 1994, Samson & Omielan, 1992).

While trees have the potential to be used as alternative energy crops, they are still relatively expensive in comparison to conventional forms of energy. A study done by the Organization for Economic Co-operation and Development (OECD) revealed that generating a kilowatt-hour of electricity from wood results in only about 10-20% of the greenhouse gas emissions that result from existing electricity generation in Europe or the United States. The electricity, though, comes out at 20-80% more expensive than power generated with existing fossil fuels (assuming no subsidy to wood production) (Michaelis, 1994). Thus, in the bigger scheme of things, producers of energy crops may recoup some of their expenses but the overall costs of producing alternative energy may be exorbitant. If overall cost recovery is to occur in this way, major improvements need to be made in the technology used to produce biomass energy.

Another way of recovering costs is to use trees in the production of ethanol. At present ethanol is used as a blending ingredient in gasolines or as a raw material to produce high-octane fuel ether additives. To date ethanol has primarily been produced from wheat in Canada, corn and other starch crops in the United States, and from rapeseed oil in Europe. The production cost of corn ethanol ranges from 35¢ to 58¢ per litre of gasoline substituted, wheat ethanol costs 35¢ - 45¢ per litre to produce, and rapeseed oil methyl ester (RME or biodiesel) costs 50-60¢ per litre diesel replaced (prices quoted in U.S.$). For wheat-based ethanol, recent Canadian estimates of energy efficiency range from 150 to 180 percent depending on production methods used, while corn-based ethanol is 110 to 125 percent (Girt, 1995)

The possibility of using tree crops for the production of ethanol is limited. In theory it is possible to do so but in practice the only ethanol produced from trees has been in the laboratory. So far it has been calculated that the production of ethanol from wood biomass would cost between 26¢ and 70¢ (CD$) per litre of ethanol produced[11] (Freeze, 1995). Besides the cost of producing ethanol, the major hindrance to using wood for its production is the technology. This technology is fundamentally different from that for ethanol produced from food crops and high costs will be incurred in converting ethanol plants to ones which can process woody biomass. According to a study by Lynd, et al., (1991) a cost-competitive process appears to be possible by about 2000.

Research and development has also been conducted using wood for the production of methanol in Hearst, Ontario. This project was technically successful but had to be abandoned due to economic disadvantages. The predicted production cost of wood methanol was projected to be 18¢ per litre in comparison to a price of 13¢ per litre for natural gas methanol in 1993 (Duff, et al., 1993). The same arguments for cost recovery with biomass energy apply to the production of ethanol. A by-product of ethanol produced from cereal crops, however, is a high-protein cake usually sold as animal feed

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[11] This cost estimate varies according to the method used for producing ethanol from wood

Ethanol Scenarios:	Acid hydrolysis with glucose fermentation	Enzyme hydrolysis with glucose fermentation	Simultaneous Saccharification with separate fermentation of glucose and xylose	Simultaneous Saccharification with co-fermentation of glucose and xylose
Cost in $ per litre of ethanol produced	0,70	0.63	0.37	0.26

(Freeze, 1995)

Cost of producing ethanol from corn stover (US $30 per dry tonne)

Process	Costs of ethanol in US cents per litre
Concentrated acid: separate fermentation	43
APEX-10: 10% solids in enzyme hydrolysis, 98% cellulose conversion, separate C5 and C6 fermentation.	31
MAFEX: 10% solids in enzyme hydrolysis, 80% cellulose conversion, separate C5 and C6 fermentation	30
Bioenergy with AFEX-10 pretreatment, 98% cellulose conversion, combined C5 and C6 fermentation	31
Bioenergy with MAFEX with sugar evaporator combined C5 and C6 fermentation, higher glucose concentration, high yields of ethanol	25
MAFEX with *Pichia stiptis* yeast, high cellulose hydrolysis yields, combined C5 and C6 fermentation with high yields	

(Freeze, 1995)

which sometimes fetches a higher price than ethanol itself. The by-product which results from producing wood ethanol, though, poses a waste disposal challenge which is also potentially costly (Girt, 1995; Michaelis, 1994; DOE, 1994).

Carbon Credits

Potentially, the amount of carbon extracted from the atmosphere through the planting of trees could qualify as a carbon credit and be sold on a carbon credit market. Producers of trees could then use the money earned on the emissions market to offset the costs of establishing and maintaining their trees. The only experimentation with emissions trading so far has been in the United States where sulphur dioxide credits are traded. The way the market works is that factories discharging less sulphur dioxide than the regulated level are accredited with an emission reduction credit. These factories are then able to sell their credit to another factory which buys the right to emit that amount of sulphur dioxide into the atmosphere.

Setting up a market for carbon credits is quite a complicated undertaking. To begin with, for the market to operate well there need to be enough players. It is uncertain how many players are actually necessary and a United Nations Conference on Trade and Development (UNCTAD) study is of the opinion that a global market would be necessary to fulfill this condition. Furthermore, the commodity needs to be well defined and the barriers to trading minimized. Barriers to trading include trading costs, search costs, and counterparty risks. Because of the high risk involved, the market needs to be supported by escrow agents, letters of credit, legal opinions and other structures which also push the costs up of participating in the market. Legal uncertainties and transferability constraints would also hinder the establishment of a successful global CO_2 emissions credit market (UNCTAD, 1994; Hansen & Roland, 1990). Without a strong legal framework and method of enforcement there will be no incentive for buyers and sellers to trade.

If all the constraints mentioned above could be minimized or overcome, then it is estimated that annually an $8.35 billion global CO_2 credit market at $10 per ton could be created. This would be assuming that the goal of stabilizing CO_2 emissions at 1990 levels by the year 2000 is used. Assuming that the U.S. were to set up an internal CO_2 emission market and establish an emissions cap of 1,530 million tonnes of carbon per year, then allowing a five year implementation period would result in carbon credits costing between $2 and $22 per tonne in the U.S. As yet no market for carbon emission credits has been established by individual states or on an international level (UNCTAD, 1994).

Planting trees for carbon emission credits has its difficulties. What happens when the trees die or are harvested? Would farmers be required to buy carbon credits in order to harvest their trees? Ascertaining how much carbon has been fixed by trees is also difficult and cannot be established with much certainty[12] (Greene, 1993). This increases the costs

[12] The dynamics of tree growth vary with tree species, soil, water and weather conditions, and tree age so that actual carbon accretion rates depend on forest type and the time frame of analysis.

of participating in a carbon emission credit market. Additional rules have to be established which increase transaction costs, as does the time and effort involved in collecting reliable data on the amount of carbon sequestered by the trees in question. Furthermore, the possibility of allowing carbon fixed through trees to be included in the market will depend on a nation’s climate change policy. If a nation’s policy is to conserve energy and promote the use of more efficient technologies then swapping the sink capacities of trees for the right of manufacturers and others to emit carbon will not achieve that goal. If, however, the policy is just to maintain levels of carbon at what they are then this could be a valid option.

Cost Structures

If emitters of carbon dioxide are required to reduce or offset their emissions they are going to choose the most cost-effective way of doing so. To determine whether planting trees on the prairies is a cost-effective method of offsetting carbon it is necessary to know what other methods are available to corporations and what they would cost per tonne of carbon reduced or offset. The options open to various corporations will depend on what industry they are involved in. Options for reducing emissions include fuel switching, and adopting alternative energy technologies such as biomass energy, solar, wind, or nuclear energy. Reducing emissions can also be done by installing energy efficient technologies. These are specific to the industry and the plant in question and are difficult to attach a price to without an in-depth knowledge of the situation. An overview of the kind of options which should be considered when establishing a cost structure for combating rising carbon dioxide levels in the energy sector is provided in Table 4.

Various organizations have already engaged in carbon sequestration projects which involve the planting of trees. These include PacifiCorp projects in Oregon and Utah in the U.S.; and joint implementation projects by AES Thames (a subsidiary of AES Corporation) in Guatemala; AES Barbers Point in Paraguay; the Forest Absorbing Carbon Dioxide Emissions (FACE) Foundation (established by the Dutch Electricity Generating Board) in Malaysia; the Global Environmental Facility (GEF) in Ecuador; the New England Electric System (NEES) in Malaysia; and the Tenaska Saratov Project in Russia. The costs of these projects in US $ are tabulated in Table 5.

Table 4. A Taxonomy of Interventions in the Energy Sector.

Option	Production/genera-tion	Transmission & distribution	End-use
• Reduce energy consumption of existing processes by increasing efficiency	• Refurbish old power plants • Repower old power plants	• Reduce T & D losses in electrical grids	• Reduce energy intensity of basic materials production • Efficient motors and drives • Irrigation pumpsets • Vehicular fuel efficiency • Process heating and cooling • Energy conservation
• Reduce emissions from existing processes	• Reduce associated gas flaring • Use coalbed methane • Collect CO_2 from fossil-fuel systems and store in depleted gas/oil fields or in deep ocean	• Reduce leaks in natural gas pipelines	• Install end-of-pipe emissions controls in wood-stoves, cars (e.g., catalytic converters)
• Switch to more energy-efficient processes	• Biomass gasifiers - gas turbines • Advanced efficient gas turbine cycles • Clean coal technologies	• HVDC transmission • Promote inter-regional flows of natural gas and hydro-electricity	• Lighting (CFLs) • Transport modal shifts (road to rail, personal to mass) • Innovative technologies for appliances, vehicles • Improved cookstoves • Land-use planning • Infrastructure efficiency
• Switch to lower emission processes	• Photovoltaics • Biomass • Wind farms • Solar thermal • Small hydro • Geothermal • Fuel cells • H_2 from non-fossil electricity • Methanol from flared gas • Nuclear • MHD generators	• Hydrogen as an energy carrier	• Solar water heating • CNG transport • Electric vehicles • Natural gas-fired engine-driven cooling systems

Note: T & D = transmission and distribution, HVDC = high-voltage direct current, CFL = compact fluorescent lamps, CNG = compressed natural gas, H_2 = hydrogen, MHD = magneto-hydro dynamics.

Source: Anhuja (1993)

Table 5. Costs and benefits of carbon offset projects at eight locations worldwide.

Project Location	U.S.A. Oregon	U.S.A. Utah	Guatemala	Paraguay	Malaysia	Ecuador	Malaysia	
Principal Sponsor	PacifiCorp	PacifiCorp	AES Thames	AES Barbers Point	NEES	GEF	FACE	Tenaska
Project	Sustainable Forestry	Urban Tree Planting	Sustainable Agroforestry	Preservation/ Sustainable Agroforestry	Sustainable Forestry	Forestation/ Forest Protection	Reforestation	Forestation
Total Costs	\$100,000 /yr	\$100,000 /yr	\$14 million	\$2-5 million	\$450,000	--	\$1.3 million	\$500,000 - ?
Utility Contri-butions	\$100,000 /yr	\$100,000 /yr	\$2 million	\$2 million	\$450,000	--	\$1.3 million	\$500,000 - ?
Other Participants	Oregon Department of Forestry	Tree Utah	CARE, Guatemala Government	Nature Conservancy, FMB Foundation	Rain Forest Alliance, COPEC	Durini Group	Innoprise	--
C Sequestered (Mg)	64,750 Mg/yr	N/A	15.5 - 58 million	13.1 million	300,000 - 600,000	375,000	--	500,000 - ?
Project Size (ha)	140	1,000 trees	52 x 10^6 trees	56,800	1,400	6,000	--	20,000 - ?
\$/Mg C Sequestered	\$5	\$15 - \$ 30	\$9 overall \$1 AES	\$1.5	less than \$2	\$3 - \$4	--	\$1 - \$2
Project Duration (yr)	65	50	10	30	10	--	--	25
Local Benefits	Assist land owners in productive land management activities	Reduce cooling and heating needs of the community, contribute to the aesthetics of the area	Promote soil and biomass conservation, develop sustainable forestry groups to protect, plant and manage trees, establish a fund to promote continuing agroforestry activities	Create a watershed, promote biodiversity, create sustainable agroforestry opportunities for inhabitants, promote recreation and eco-tourism opportunities	Train local inhabitant in sustainable logging activities, preserving non-harvested trees, improve water quality, maintain biodiversity, reduce soil erosion	Foster local forest management, preserve forest	Promote biomass and soil conservation, landscape protection	Habitat improvement, soil and water conservation, and transition to regional market economy

Source: Dixon et al. (1993)

Conclusions and Recommendations

Conclusions

While the decision is still being reached about the impacts of climate change, it can be said that the ratio of greenhouse gases is increasing in our atmosphere. In this report policies and practices in Canada, the United States and the European Union were reviewed to find out what is being done to control the carbon dioxide ratio in the atmosphere. It is apparent that this is an issue of concern in all of these countries. In Canada, little has been done in terms of policy that has direct influence on carbon dioxide in the atmosphere. In this study, three ways to combat rising CO_2 emissions have been considered: substitution of lower carbon energy sources, reduction of the activity causing the emissions and finally sequestration of carbon dioxide.

Tree planting is part of a larger strategy for fighting rising CO_2 levels. Canada's commitment to reduce CO_2 levels in the atmosphere cannot acceptably be handled by trees alone, however. Tree planting should be used in conjunction with reducing emissions through the use of fuel switching, adoption of more energy efficient technologies, alternative energy sources and improved farming practices. Despite progress being made in developing technologies that are more energy efficient, if economies continue to grow, and the rate of production with it, striving after energy efficiency may be a short-term measure in fighting emissions. A more appropriate long-term measure would be replacement of fossil fuels with alternative fuels.

The substitution of high carbon energy sources with low carbon energy sources shows promise in reducing Canada's carbon dioxide emissions. This can be done by replacing coal and oil with natural gas or by moving towards non-fossil fuels such as wood, ethanol and other energy sources like hydro, wind, solar, geothermal, nuclear and tidal.

The final method is to reduce CO_2 emission by limiting production processes that produce CO_2. These reductions would also have an effect on consumption patterns and sources of energy. Most studies conclude that a reduction in energy use is the most effective method of reducing CO_2 emissions.

This being said, tree planting is still a viable component because of its other inherent benefits. Trees offer possibilities for reducing energy requirements in an urban and rural setting, erosion control, harvestable produce such as fruit and wood, increased biodiversity, aesthetics, and recreation. Carbon sequestration is an added benefit. In order for this benefit to be a lasting one, tree-planting initiatives need to be sustained over the long-term.

One policy implication of fighting rising CO_2 levels is that taxes used as an incentive to induce lower energy use need to be very high. This is politically unfeasible. Another is that the manner in which resources are managed could be affected if trees and grasslands become more valuable for carbon sequestration than for the economic values gained from timber harvesting and agricultural production. Resource management and development policies must be sensitive to the carbon factor.

Recommendations

There is still substantial uncertainty as to how much it will cost to use trees as a carbon sink. However, there is evidence that trees play an important role in the reduction of energy use and carbon dioxide emissions. The planting of trees as shelterbelts to reduce wind erosion is a well-documented benefit. The effectiveness of trees in an urban setting has also been noted. New technology in the production of ethanol from biomass has significant implications on the role of trees as an energy source. Given the results of this study, the recommendations are as follows:

1) Trees should be evaluated for their effectiveness in removing carbon dioxide from the atmosphere and storing it, not only in its own biomass, but also the amount of carbon that is transferred to the soil.

2) More research should be conducted on the feasibility of using trees' biomass as an alternative source of energy, either as ethanol or in power generation.

3) A better understanding of the carbon cycle in an agricultural context is required to determine if agriculture on the prairies is a net source or sink of carbon. A fair amount of work is being done by agronomists in this area. However, what is lacking is a comparison of how the sink capacities of agriculture compare to that of trees.

4) A comprehensive list/database of what studies and actions are going on in relation to CO_2 sequestration on the prairies and elsewhere would be useful.

5) Research is required to determine the acceptability of a carbon credit market. If a carbon credit market is to be set up, there needs to be strong legislation which helps define the commodity and sets the rules of the market. If emitters of carbon are not required to buy credits in order to emit carbon dioxide, there is no incentive for the market to work. Also, those involved in fixing carbon need to look at what it will cost them to fix carbon and set the price for the credits they sell accordingly, rather than based on what the buyer is willing to pay.

6) Finally, with climate change also comes the prospect of increasing weather variability. There is still much uncertainty as to the degree of variability that can be expected and what all the impacts of it will be. In formulating policy for climate change, attention also needs to be devoted to how policy can encourage communities and individuals to adapt to their changing environment and cope with uncertainty.

7) A detailed assessment of other options for carbon sequestration should be made. Their efficiencies plus the costs for power generation, transmission, and use also need to be examined.

For these recommendations to be effective, there needs to be an increased public awareness of the value of trees on the prairies. Some groups do not consider tree planting as a valid action for fighting carbon emissions and climate change. For this kind of measure to be publicly acceptable as a government action a good marketing strategy will be necessary.

Glossary

Afforestation: Planting trees to form a forest, usually on land that has not been forested before.

Biofuels: Biofuels are alcohols, ethers and other chemicals made from cellulosic biomass - renewable resources such as fast growing trees, grasses, aquatic plants, and waste products, such as agricultural and forestry residues, and municipal and industrial wastes.

Biomass: Biomass is found in trees, grasses, and ocean plants. Biomass is produced from these growing living plants through photosynthesis - the process by which plant matter is formed using the energy of sunlight.

Carbon Cycle: The cycle of carbon in its different chemical forms in the atmosphere, the biosphere, hydrosphere and in the lithosphere.

Carbon Sequestration: The removal and long-term storage of atmospheric carbon in soils and biomass.

CO_2: The chemical formula for carbon dioxide.

Cogeneration: Cogeneration occurs when a power generating station is used to produce more than one type of energy, e.g., electricity and heat.

Global Climate Change: refers to a theory; if the amount of CO_2 and other trace greenhouse gases in the atmosphere are increased, more heat will be trapped potentially causing a variety of changes to current climate patterns, temperature, and atmospheric processes.

Global Warming: Global warming - or its opposite, global cooling - is a long-term change in the average temperature of the Earth.

Greenhouse Effect: is a natural phenomenon by which Earth's atmosphere traps and holds warmth from the sun. The Earth's surface absorbs the solar radiation that reaches it and then radiates heat back into the atmosphere. Trace gasses (CO_2, ozone, methane, oxides of nitrogen, and others) that exist in the Earth's atmosphere absorb and bounce back much of the planets radiated heat before it escapes into space. CO_2 exists in the atmosphere in far larger quantities than other trace gases and is thus responsible for more than half the Earth's greenhouse effect. Without the process the Earth's temperature would be about $33^{o}C$ cooler and unable to support life as we know it.

Greenhouse Gases: are carbon dioxide (CO_2), methane, nitrous oxides, and hydroflourocarbons (HFCs).

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Appendices

Appendix A. Above Ground Biomass in kg/tree by Species and Soil Zone.

Above Ground Biomass in kg/tree and Carbon percentages of four shelterbelt species in three soil zones.

Soil Zones	**Green Ash 48.6% Carbon**	**Manitoba Maple 48.0% Carbon**	**Hybrid Poplar 48.2% Carbon**	**Siberian Elm 49.4% Carbon**
Brown	98.46	120.44	423.63	131.71
Dark Brown	158.65	186.02	296.21	229.45
Black	294.17	214.62	592.04	--
Average	183.76	173.69	437.29	180.58

Source: Kort (1996).

Appendix B. Alberta Natural Unmanaged Stands.

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant-able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
White Spruce (Picea glauca)	good	20	0.8	15.3	5.7	9.3	12.5	6.3	8143	0.8
		40	2.6	103.7	38.4	62.9	85.0	42.5	2222	19.1
		60	3.5	207.9	76.9	126.2	170.3	85.2	1400	60.8
		80	3.8	301.6	111.6	183.0	247.0	123.5	1059	116.6
		100	3.8	376.4	139.3	228.4	308.3	154.2	866	178.0
		120	3.6	433.8	160.5	263.2	355.3	177.7	741	239.8
		140	3.4	477.5	176.7	289.7	391.1	195.6	654	299.0
		160	3.2	511.0	189.1	310.1	418.6	209.3	590	354.8
		180	3.0	537.2	198.8	326.0	440.1	220.0	542	406.0
	medium	20	0.2	4.0	1.5	2.5	3.3	1.7	20497	0.1
		40	1.4	56.0	20.7	34.0	45.9	22.9	3334	6.9
		60	2.1	124.6	46.1	75.6	102.0	51.0	1972	25.9
		80	2.4	195.2	72.2	118.5	159.9	80.0	1463	54.7
		100	2.6	259.9	96.1	157.7	212.9	106.4	1191	89.4
		120	2.6	315.3	116.7	191.3	258.3	129.2	1020	126.6
		140	2.6	361.5	133.8	219.4	296.2	148.1	901	164.3
		160	2.5	399.5	147.8	242.4	327.3	163.6	814	201.0
		180	2.4	430.7	159.4	261.4	352.9	176.4	748	235.9
	poor	20	0.0	0.0	0.0	0.0	0.0	0.0	0	
		40	0.5	21.5	8.0	13.1	17.6	8.8	6414	1.4
		60	1.0	56.8	21.0	34.5	46.6	23.3	3301	7.1
		80	1.2	97.7	36.2	59.3	80.0	40.0	2310	17.3
		100	1.4	140.7	52.0	85.3	115.2	57.6	1821	31.6
		120	1.5	183.1	67.7	111.1	150.0	75.0	1529	49.0
		140	1.6	223.3	82.6	135.5	182.9	91.4	1332	68.6
		160	1.6	260.3	96.3	157.9	213.2	106.6	1190	89.6
		180	1.6	293.7	108.7	178.2	240.6	120.3	1082	111.2
Black Spruce (Picea mariana)	good	20	1.0	19.6	7.2	11.9	16.0	8.0	56200	0.1
		40	2.7	109.6	40.6	66.5	89.8	44.9	8932	5.0
		60	3.2	189.3	70.1	114.9	155.1	77.6	4958	15.6
		80	3.2	256.6	95.0	155.7	210.2	105.1	3494	30.1
		100	3.1	312.2	155.5	189.4	255.7	127.9	2730	46.8
		120	3.0	357.8	132.4	217.1	293.1	146.6	2261	64.8
		140	2.8	395.5	146.3	240.0	324.0	162.0	1943	83.4
		160	2.7	426.7	157.9	258.9	349.6	174.8	1714	102.0
		180	2.5	452.9	167.6	274.8	371.0	185.5	1540	120.5
	medium	20	0.1	2.8	1.0	1.7	2.3	1.2	479990	0.0
		40	1.3	52.6	19.5	31.9	43.1	21.5	19413	1.1
		60	1.7	99.9	37.0	60.6	81.8	40.9	9852	4.2
		80	1.8	144.4	53.4	87.6	118.3	59.1	6660	8.9
		100	1.9	185.6	68.7	112.6	152.1	76.0	5069	15.0
		120	1.9	223.3	82.6	135.5	182.9	91.5	4116	22.2
		140	1.8	257.5	95.3	156.2	210.9	105.5	3480	30.3
		160	1.8	288.3	106.7	175.0	236.2	118.1	3026	39.0
		180	1.8	316.2	117.0	191.8	259.0	129.5	2685	48.2
	poor	20	0.0	0.0	0.0	0.0	0.0	0.0	0	
		40	0.6	24.0	8.9	14.6	19.7	9.8	45047	0.2
		60	0.9	51.1	18.9	31.0	41.8	20.9	20039	1.0
		80	1.0	77.7	28.7	47.1	63.6	31.8	12848	2.5
		100	1.0	103.8	38.4	63.0	85.0	42.5	9465	4.5
		120	1.1	129.2	47.8	78.4	105.8	52.9	7504	7.0
		140	1.1	153.7	56.9	93.3	125.9	63.0	6226	10.1
		160	1.1	177.4	65.6	107.7	145.3	72.7	5328	13.6
		180	1.1	200.1	74.0	121.4	163.9	82.0	4661	17.6

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant -able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
Pine (Pinus sp.)	good	20	2.9	58.3	21.6	35.4	47.8	23.9	15982	1.5
		40	4.7	189.1	70.0	114.8	154.9	77.5	3347	23.1
		60	4.8	290.2	107.4	176.1	237.7	118.9	1798	66.1
		80	4.5	362.7	134.2	220.1	297.1	148.5	1243	119.5
		100	4.2	414.7	153.4	251.6	339.7	169.8	966	175.8
		120	3.8	452.9	167.6	274.8	371.0	185.5	803	231.0
		140	3.4	481.8	178.3	292.4	394.7	197.4	696	283.6
		160	3.2	504.2	186.6	306.0	413.1	206.5	621	332.6
		180	2.9	522.0	193.1	316.7	427.6	213.8	565	378.4
	medium	20	1.8	36.0	13.3	21.9	29.5	14.7	30366	0.5
		40	3.3	130.1	48.1	78.9	106.6	53.3	5543	9.6
		60	3.5	209.2	77.4	126.9	171.4	85.7	2909	29.5
		80	3.4	270.7	100.1	164.2	221.7	110.9	2001	55.4
		100	3.2	317.9	117.6	192.9	260.4	130.2	1555	83.7
		120	3.0	354.3	131.1	215.0	290.3	145.1	1295	112.1
		140	2.7	383.0	141.7	232.4	313.7	156.9	1126	139.3
		160	2.5	405.9	150.2	246.3	332.5	166.2	1008	164.9
		180	2.4	424.5	157.0	257.6	347.7	173.9	922	188.6
	poor	20	1.0	19.7	7.3	11.9	16.1	8.1	68585	0.1
		40	2.0	80.2	29.7	48.7	65.7	32.8	10501	3.1
		60	2.3	135.1	50.0	82.0	110.7	55.3	5271	10.5
		80	2.3	181.6	67.2	110.2	148.8	74.4	3539	21.0
		100	2.2	220.0	81.4	133.5	180.2	90.1	2709	33.3
		120	2.1	251.6	93.1	152.7	206.1	103.1	2231	46.2
		140	2.0	277.8	102.8	168.6	227.5	113.8	1924	59.1
		160	1.9	299.5	110.8	181.8	245.4	122.7	1711	71.7
		180	1.8	317.8	117.6	192.9	260.4	130.2	1556	83.7
Hardwoods	good	20	3.4	68.7	34.3	56.3	76.0	38.0	3062	12.4
		40	4.2	169.6	84.8	139.1	187.7	93.9	1252	75.0
		60	4.2	254.3	127.1	208.5	281.5	140.7	822	171.2
		80	4.0	317.0	158.5	259.9	350.9	175.4	634	276.7
		100	3.6	362.4	181.2	297.2	401.2	200.6	530	378.5
		120	3.3	395.8	197.9	324.6	438.2	219.1	464	472.1
		140	3.0	420.9	210.5	345.2	466.4	233.0	420	554.7
		160	2.8	440.3	220.1	361.0	487.4	243.7	388	628.1
		180	2.5	455.5	227.8	373.5	504.2	252.1	365	690.8
	medium	20	2.4	47.1	23.5	38.6	52.1	26.0	4562	5.7
		40	3.0	118.7	59.4	97.3	131.4	65.7	1775	37.0
		60	3.0	181.7	90.8	149.0	201.1	100.5	1169	86.0
		80	2.9	230.9	115.4	189.3	255.6	127.8	913	140.0
		100	2.7	268.2	134.1	219.9	296.9	148.4	774	191.8
		120	2.5	296.6	148.3	243.2	328.3	164.2	688	238.6
		140	2.3	318.5	159.3	261.2	352.6	176.3	630	279.9
		160	2.1	335.8	167.9	275.3	371.7	185.9	588	316.1
		180	1.9	349.6	174.8	286.7	387.0	193.5	557	347.4
	poor	20	1.5	30.2	15.1	24.7	33.4	16.7	7503	2.2
		40	1.9	77.2	38.6	63.3	85.5	42.7	2718	15.7
		60	2.0	119.8	59.9	98.2	132.6	66.3	1760	37.7
		80	1.9	154.6	77.3	126.8	171.2	85.6	1371	62.4
		100	1.8	182.2	91.1	149.4	201.7	100.9	1165	86.6
		120	1.7	204.0	102.0	167.3	225.8	112.9	1039	108.7
		140	1.6	221.3	110.7	181.5	245.0	122.5	955	128.3
		160	1.5	235.3	117.6	192.9	260.5	130.2	895	145.5
		180	1.4	246.7	12.3.	202.3	273.1	136.5	850	160.6

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant -able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
Mixed Wood (Coniferous component)	good	20	0.4	7.0	3.1	5.1	6.8	3.4	572	6.0
		40	1.4	55.0	24.2	39.7	5.3.6	26.8	683	39.2
		60	2.1	127.2	56.0	91.8	123.9	61.9	691	89.6
		80	2.6	206.0	90.6	148.6	200.6	100.3	691	145.2
		100	2.8	278.1	122.4	200.7	270.9	135.5	679	199.8
		120	2.8	338.7	149.0	244.4	329.9	165.0	658	250.7
		140	2.8	387.6	170.5	279.7	377.6	188.8	636	296.8
		160	2.7	426.7	187.8	307.9	415.7	207.8	614	338.5
		180	2.5	458.0	201.5	330.5	446.2	223.1	593	376.2
	medium	20	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		40	0.7	27.6	12.1	19.9	26.9	13.4	681	19.7
		60	1.1	68.1	30.0	49.2	66.4	33.2	685	48.4
		80	1.5	117.5	51.7	84.8	114.5	57.2	691	82.8
		100	1.7	169.3	74.5	122.1	164.9	82.4	693	119.0
		120	1.8	218.7	96.2	157.8	213.0	1065	689	154.6
		140	1.9	263.2	115.8	189.9	256.4	128.2	681	188.2
		160	1.9	302.0	132.9	217.9	294.2	147.1	671	219.2
		180	1.9	335.4	147.6	242.0	326.7	163.3	659	247.9
	poor	20	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		40	0.3	13.5	5.9	9.7	13.2	6.6	662	9.9
		60	0.6	35.6	15.7	25.7	34.7	17.3	682	25.4
		80	0.8	63.9	28.1	46.1	62.2	31.1	684	45.5
		100	1.0	96.2	42.3	69.4	93.7	46.9	688	68.1
		120	1.0	130.5	57.4	94.2	127.2	63.6	692	91.9
		140	1.2	164.9	72.6	119.0	160.7	80.3	693	115.9
		160	1.2	198.0	87.1	142.9	192.9	96.4	691	139.6
		180	1.3	228.9	100.7	165.2	223.0	111.5	688	162.1
Mixed Wood (Deciduous component)	good	20	0.6	11.4	5.0	8.3	11.1	5.6	512	10.9
		40	1.3	53.0	23.3	38.3	51.6	25.8	355	72.7
		60	1.9	112.4	49.5	81.1	109.5	54.8	313	174.9
		80	2.0	155.7	68.5	112.3	151.6	75.8	297	255.3
		100	1.8	177.5	78.1	128.1	172.9	86.5	290	298.1
		120	1.6	185.6	81.7	133.9	180.8	90.4	288	313.9
		140	1.3	186.7	82.1	134.7	181.8	90.9	287	316.8
		160	1.2	184.5	81.2	133.1	179.7	89.9	288	312.1
		180	1.0	181.1	79.7	130.7	176.4	88.2	289	305.2
	medium	20	0.4	7.8	3.4	5.7	7.6	3.8	555	6.9
		40	0.7	28.1	12.4	20.3	27.4	13.7	405	33.8
		60	1.1	64.9	28.6	46.8	63.2	31.6	342	92.4
		80	1.3	105.5	46.4	76.1	102.8	51.4	316	162.6
		100	1.4	138.4	60.9	99.9	134.8	67.4	303	222.4
		120	1.3	160.6	70.7	115.9	156.5	78.2	295	265.2
		140	1.2	174.2	76.6	125.7	169.7	84.8	291	291.5
		160	1.1	181.7	79.9	131.1	177.0	88.5	289	306.2
		180	1.0	185.4	81.6	133.8	180.6	90.3	288	313.5
	poor	20	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
		40	0.4	16.3	7.2	11.8	15.9	8.0	465	17.1
		60	0.6	35.3	15.5	25.5	34.4	17.2	385	44.6
		80	0.8	61.1	26.9	44.1	59.5	29.7	346	86.0
		100	0.9	89.0	39.2	64.2	86.7	43.4	325	133.4
		120	1.0	114.7	50.5	82.8	111.8	55.9	312	179.1
		140	1.0	136.0	59.8	98.1	132.5	66.2	304	217.9
		160	1.0	152.3	67.0	109.9	148.4	74.2	298	248.9
		180	0.9	164.3	72.3	118.5	160.0	80.0	294	272.1

Data from Alberta Phase 3 Forest Inventory: yield tables for unmanaged stands. 1985

Appendix C. Saskatchewan Mixed Wood Forest.

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant-able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
White Spruce	good	70	4.3	301.0	111.4	182.6	246.6	123.3	1059	116.4
(Picea Glauca)	medium	75	3.1	232.5	86.0	141.1	190.5	95.2	1463	65.1
	poor	80	2.0	160.0	59.9	97.1	131.1	65.5	1821	36.0
Black Spruce	good	90	2.0	180.0	66.6	109.2	147.5	73.7	4958	14.9
(Picea mariana)	medium	100	1.4	140.0	51.8	85.0	114.7	57.3	6660	8.6
	poor	120	0.8	96.0	35.5	58.3	78.6	39.3	9465	4.2
Jack Pine	good	65	2.7	175.5	64.9	106.5	143.8	71.9	1480	48.6
(Pinus banksiana)	medium	70	2.0	140.0	51.8	85.0	114.7	57.3	1500	38.2
	poor	80	1.3	104.0	38.5	63.1	85.2	42.6	1678	25.4
Tamarack	medium	100	0.8	80.0	29.6	48.5	65.5	32.8	2700	12.1
(Lanix laracina)										
Aspen	good	60	3.5	210.0	105.0	172.2	232.5	116.2	1037	112.1
(Populus sp.)	medium	70	2.8	196.0	98.0	160.7	217.0	108.5	1150	94.3
	poor	80	2.0	160.0	80.0	131.2	177.1	88.6	1371	64.6
Spruce-Aspen	good	70	4.1	287.0	120.5	197.7	266.9	133.4	678	196.8
(50-75% softwood)	medium	75	3.1	232.5	97.7	160.1	216.2	108.1	685	157.8
	poor	80	2.6	208.0	87.4	143.3	193.4	96.7	690	140.2
Aspen-Spruce	good	65	3.7	240.5	108.2	177.5	239.6	119.8	685	174.9
(50-75% hardwood)	medium	70	2.9	203.0	91.4	149.8	202.2	101.1	691	146.3
	poor	80	2.0	160.0	72.0	118.1	159.4	79.7	693	115.0
Jack Pine-Aspen	good	65	2.9	188.5	79.2	129.8	175.3	87.6	691	126.8
(50-75% softwood)	medium	70	2.2	154.0	64.7	106.1	143.2	71.6	693	103.3
	poor	80	1.5	120.0	50.4	82.7	111.6	55.8	692	80.6
Aspen-Jack Pine	good	60	3.3	198.0	89.1	146.1	197.3	98.6	691	142.7
(50-75% hardwood)	medium	70	2.6	182.0	81.9	134.3	181.3	90.7	692	131.0
	poor	80	1.8	144.0	64.8	106.3	143.5	71.7	693	103.5

Data from Technical Bulletin No. 8, Canada-Saskatchewan Forest resource development Agreement, 1986.

* stems per hectare estimated based on data from Alberta stands for similar site, volume, and age.
Jack pine and larch density estimates based on Ontario data

Appendix D. Manitoba Unmanaged Stands (except Scotch Pine).

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
Manitoba Aspen Parkland										
Trembling Aspen	good	60	1.7	100.2	50.1	82.2	110.9	55.5	1775	31.2
(Populus tremuloides)	medium	60	1.0	62.4	31.2	51.2	69.1	34.5	2718	12.7
White Birch	good	60	1.7	102.0	51.0	83.6	112.9	56.5	1441	39.2
(Betula papynifera)										
Ash	good	60	2.7	159.6	79.8	130.9	176.7	88.3	N/A	-
(Fraxinus sp.)	medium	60	0.9	52.2	26.1	42.8	57.8	28.9	N/A	-
Oak	medium	60	1.1	64.8	32.4	53.1	71.7	35.9	N/A	-
(Quercus sp.)										
Manitoba Maple	good	60	1.4	83.4	41.7	68.4	92.3	46.2	N/A	-
(Acer negundo.)										
Balsam poplar	good	60	1.9	116.4	48.9	80.2	108.2	54.1	1775	30.5
(Populus balsamifera)										
Basswood	good	60	3.3	196.8	98.4	161.4	217.9	108.9	N/A	-
(Tilia americana)										
Scotch Pine Plantation	medium	60	2.36	141.6	52.4	85.9	116.0	58.0	1400	41.4
(Pinus sylvestris)										
Manitoba Mountain Forest										
White Spruce	good	100	1.9	192.0	71.0	116.5	157.3	78.6	2454	32.0
(Picea glauca)										
Black Spruce	good	80	2.2	172.0	63.6	104.4	140.9	70.4	2414	29.2
(Picea mariana)	medium	140	0.6	82.6	30.6	50.1	67.7	33.8	3300	10.3
Jack Pine	good	60	3.3	198.0	73.3	120.1	162.2	81.1	1400	57.9
(Pinus banksiana)	medium	60	1.4	85.2	31.5	51.7	69.8	34.9	2270	15.4
Tamarack	good	90	1.0	89.1	33.0	54.1	73.0	36.5	2670	13.7
(Larix laracina)										
Balsam Fir	good	60	2.5	147.0	54.4	89.2	120.4	60.2	2866	21.0
(Abies balsamea)										
Trembling Aspen	good	55	2.6	141.4	70.7	115.9	156.5	78.2	1650	47.4
(Populus tremuloides)										
White Birch	good	50	2.0	101.5	50.8	83.2	112.4	56.2	1440	39.0
(Betula papyrifera)										
Elm	good	50	3.2	157.5	78.8	129.2	174.4	87.2	N/A	-
(Ulmus americana)										
Oak	good	50	0.9	47.0	23.5	38.5	52.0	26.0	N/A	-
(Quercus sp.)										
Manitoba Maple	good	50	4.0	202.0	101.0	165.6	223.6	111.8	N/A	-
(Acer negundo)										
Balsam poplar	good	50	2.5	125.0	52.5	86.1	116.2	58.1	1700	34.2
(Populus balsamifera)										
Manitoba Pineland Forest										
Red Pine	good	80	2.3	185.6	68.7	112.6	152.0	76.0	960	79.2
(Pinus resinosa)										
Jack Pine	good	60	2.0	121.2	44.8	73.5	99.3	49.6	1482	33.5
(Pinus banksiana)	medium	60	1.2	69.6	25.8	42.2	57.0	28.5	2776	10.3
Black Spruce	good	80	1.4	110.4	40.8	67.0	90.4	45.2	3126	14.5
(Picea mariana)	medium	140	0.5	70.0	25.9	42.5	57.3	28.7	3500	8.2
Balsam Fir	good	60	2.1	124.2	46.0	75.4	101.7	50.9	3100	16.4
(Abies balsamea)										
Tamarack	good	90	0.8	72.0	26.6	43.7	59.0	29.5	2476	11.9
(Larix laracina)										

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant-able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
Manitoba Pineland Forest										
Eastern Cedar	good	80	1.6	124.8	46.2	75.7	102.2	51.1	2430	21.0
(Thuja occidentalis)										
Trembling Aspen	good	60	1.9	111.0	55.5	91.0	122.9	61.4	1900	32.3
(Populus tremuloides)	medium	60	1.1	63.0	31.5	51.7	69.7	34.9	2200	15.9
White Birch	good	60	1.5	87.0	43.5	71.3	96.3	48.2	1760	27.4
(Betula papyrifera)										
Elm	good	60	1.6	97.2	48.6	79.7	107.6	53.8	N/A	-
(Ulmus americana)										
Ash	good	60	2.0	118.8	59.4	97.4	131.5	65.8	N/A	-
(Fraxinus sp.)										
Balsam poplar	good	60	1.2	70.2	29.5	48.4	65.3	32.6	2150	15.2
(Populus balsamifera)										
Manitoba - Lake Winnipeg East Section										
Jack Pine	good	80	1.7	136.8	50.6	83.0	112.1	56.0	1300	43.1
(Pinus banksiana)	medium	80	1.0	83.2	30.8	50.5	68.2	34.1	2300	14.8
White Spruce	good	100	1.7	165.0	61.1	100.1	135.2	67.6	1800	37.5
(Picea glauca)										
Black Spruce	good	80	1.4	114.4	42.3	69.4	93.7	46.9	3130	15.0
(Picea mariana)	medium	140	0.6	85.4	31.6	51.8	70.0	35.0	3400	10.3
	poor	140	0.4	60.2	22.3	36.5	49.3	24.7	3700	6.7
Tamarack	good	90	1.2	105.3	39.0	63.9	86.3	43.1	2680	16.1
(Larix laracina)		140	0.6	88.2	32.6	53.5	72.3	36.1	2340	15.4
Balsam Fir	good	70	1.6	114.1	42.2	69.2	93.5	46.7	3120	15.0
(Abies balsamea)										
Eastern Cedar	good	80	2.0	157.6	58.3	95.6	129.1	64.6	2300	28.1
(Thuja occidentalis)	medium									
Trembling Aspen	good	65	2.2	142.2	71.2	116.7	157.6	78.8	1650	47.8
(Populus tremuloides)		65	1.0	67.6	33.8	55.4	74.8	37.4	2200	17.0
White Birch	good	65	1.4	88.4	44.2	72.5	97.9	48.9	1750	28.0
(Betula papyrifera)										
Elm	good	65	1.0	65.7	32.8	53.8	72.7	36.3	N/A	-
(Ulmus americana)										
Ash	good	65	1.6	105.3	52.7	86.3	116.6	58.3	N/A	-
(Fraxinus sp.)										
Balsam poplar	good	65	1.5	95.6	40.1	65.8	88.9	44.4	2000	22.2
(Populus balsamifera)										
Mixed Hardwoods	good	65	2.2	140.4	59.0	96.7	130.6	65.3	1400	46.6
	medium	65	1.3	85.8	36.0	59.1	79.8	39.9	2600	15.3
Manitoba - Interlake Section										
Red Pine	good	80	3.6	286.4	106.0	173.8	234.6	117.3	600	195.5
(Pinus resinosa)										
Jack Pine	good	60	1.6	97.8	36.2	59.3	80.1	40.1	1700	23.6
(Pinus banksiana)	medium	60	1.1	66.6	24.6	40.4	54.6	27.3	2400	11.4
White Spruce	good	80	1.7	138.4	51.2	84.0	113.4	56.7	1821	31.1
(Picea glauca)										
Black Spruce	good	80	1.5	121.6	45.0	73.8	99.6	49.8	3100	16.1
(Picea mariana)	medium	140	0.5	74.2	27.5	45.0	60.8	30.4	3700	8.2
Balsam Fir	good	60	1.5	91.8	34.0	75.2	75.2	37.6	3200	11.8
(Abies balsamea)										

Species or Stand Type	Site Type	Age	Mean Annual Increment (m3/ha)	Merchant-able Volume (m3)	Merchantable dry biomass (t/ha)	Total above-ground dry biomass (t/ha)	Total above & below ground dry biomass (t/ha)	Total Carbon (tC/ha)	Stems per hectare	Carbon per tree (kg)
Manitoba - Interlake Section										
Tamarack	good	90	1.2	104.4	38.6	63.3	85.5	42.8	2680	16.0
(Larix laracina)	medium	140	0.2	29.4	10.9	17.8	24.1	12.0	3400	3.5
Eastern Cedar	medium	140	0.7	102.2	37.8	62.0	83.7	41.9	2700	15.5
(Thuja occidentalis)										
Trembling Aspen	good	60	2.0	121.8	60.9	99.9	134.8	67.4	1900	35.5
(Populus tremuloides)	medium	60	1.0	61.8	30.9	50.7	68.4	34.2	2200	15.5
White Birch	good	60	1.8	108.0	54.0	88.6	119.6	59.8	1440	41.5
(Betula papyrifera)										
Elm	good	60	3.8	226.2	113.1	185.5	250.4	125.2	N/A	-
(Ulmus americana)										
Balsam poplar	good	60	1.8	107.4	45.1	74.0	99.9	49.9	1950	25.6
(Populus balsamifera)	medium	60	0.6	33.0	13.9	22.7	30.7	15.3	2500	6.1
Manitoba - Saskatchewan River Section										
Jack Pine	good	75	1.6	117.8	43.6	71.5	96.5	48.2	2000	24.1
(Pinus banksiana)	medium	75	0.6	44.3	16.4	26.9	36.2	18.1	3000	6.0
White Spruce	good	100	1.9	188.0	69.6	114.1	154.0	77.0	1470	52.4
(Picea glauca)	medium	100	0.6	64.0	23.7	38.8	52.4	26.2	3200	8.2
Black Spruce	good	80	1.4	115.2	42.6	69.9	94.4	47.2	3100	15.2
(Picea mariana)	medium	140	0.4	58.8	21.8	35.7	48.2	24.1	3700	6.5
Balsam Fir	good	80	1.7	136.0	50.3	82.5	111.4	55.7	2800	19.9
(Abies balsamea)										
Trembling Aspen	good	60	1.8	108.0	54.0	88.6	119.6	59.8	1950	30.7
(Populus tremuloides)										
White Birch	good	60	1.3	76.2	38.1	62.5	84.4	42.2	1650	25.6
(Betula papyrifera)	medium	60	0.4	21.0	10.5	17.2	23.2	11.6	3000	3.9
Elm	good	60	2.9	175.8	87.9	144.2	194.6	97.3	N/A	-
(Ulmus americana)										
Ash	good	60	2.3	137.4	68.7	112.7	152.1	76.1	N/A	-
(Fraxinus sp.)										
Manitoba Maple	good	60	2.8	166.8	83.4	136.8	184.6	92.3	N/A	-
(Acer negundo)										
Balsam poplar	good	60	2.7	161.4	67.8	111.2	150.1	75.0	1500	50.0
(Populus balsamifera)										
Manitoba - Highrock Section										
Jack Pine	good	80	1.7	132.8	49.1	80.6	108.8	54.4	2000	27.2
(Pinus banksiana)	medium	80	0.9	68.8	25.5	41.7	56.4	28.2	2300	12.3
White Spruce	good	100	1.8	181.0	67.0	109.8	148.3	74.1	1500	49.4
(Picea glauca)	poor	100	0.8	81.0	30.0	49.2	66.4	33.2	2400	13.8
Black Spruce	good	80	1.6	124.8	46.2	75.7	102.2	51.1	3000	17.0
(Picea mariana)	medium	140	0.5	74.2	27.5	45.0	60.8	30.4	3670	8.3
	poor	140	0.6	77.0	28.5	46.7	63.1	31.5	3600	8.8
Balsim Fir	good	80	2.2	176.8	65.4	107.3	144.8	72.4	2400	30.2
(abies balsamea)										
Mixed Hardwoods	good	80	1.8	140.8	59.1	97.0	130.9	65.5	1600	40.9
	medium	80	1.1	85.6	36.0	59.0	79.6	39.8	2400	16.6
Manitoba - Churchill River Section										
Jack Pine	good	80	0.6	48.0	17.8	39.3	39.3	19.7	3000	6.6
(Pinus banksiana)	medium	80	0.4	28.0	10.4	22.9	22.9	11.5	4500	2.5